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STATE OF CALIFORNIA—THE RESOURCES AGENCY

COLORADO RIVER BOARD OF CALIFORNIA
770 FAIRMONT AVENUE, SUITE 100
GLENDALE, CA 91203-1035
(818) 543-4676
(818) 543-4685 FAX

file

WR —

October 9, 1997

M E M O R A N D U M

CC: WR
EA
DR

TO: Members and Alternates, Agency Managers
Colorado River Board of California
Interested Parties

SUBJECT: 1996 Annual Report on the Colorado River Basin Salinity Control Program, January 1997

Attached is a copy of the 1996 Annual Report on the Colorado River Basin Salinity Control Program, January 1997, prepared by the Colorado River Basin Salinity Control Advisory Council. The report presents the Advisory Council's recommendations to the federal agencies involved in salinity control activities on appropriate means of controlling the Colorado River's salinity.

If you have any questions, please call me at (818) 543-4676.

Gerald R. Zimmerman
Executive Director,
and Chairman of Colorado River
Basin Salinity Control Forum
and Advisory Council

Attachment

1996 ANNUAL REPORT
ON THE
COLORADO RIVER BASIN
SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN
SALINITY CONTROL ADVISORY COUNCIL

January 1997

1996 ANNUAL REPORT
ON THE
COLORADO RIVER BASIN
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1996 ANNUAL REPORT
ON THE
COLORADO RIVER BASIN
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COLORADO RIVER BASIN
SALINITY CONTROL ADVISORY COUNCIL

January 1997

BACKGROUND

Public Law 93-320, also known as the "Colorado River Basin Salinity Control Act of 1974" (Act), authorized the construction, operation, and maintenance of works in the Colorado River Basin to control the salinity of Colorado River water available for use in the United States and Mexico. Section 204 of the Act established the Colorado River Basin Salinity Control Advisory Council (Council). A charter for the Council was originally approved by the Secretaries of the Departments of the Interior and Agriculture and the Administrator of the Environmental Protection Agency (EPA) on February 6, 1976. It was revised on June 22, 1976 and has been renewed biennially. The Council receives reports from the federal agencies involved in salinity control activities and makes recommendations to them regarding appropriate methods for controlling the salinity of the Colorado River at its meetings and in this annual report.

The Council is comprised of up to three members from each of the seven Colorado River Basin states. Representatives are appointed by Governors and current membership is shown on Attachment A. William J. Miller, New Mexico, acts as Chairman of the Council and Gerald R. Zimmerman, California, serves as Vice Chairman. Advisory Council membership is generally synonymous with Colorado River Basin Salinity Control Forum (Forum) membership. The Forum is an organization created in 1974 by the seven Colorado River Basin states which was established for the purpose of interstate cooperation and to provide the states with the information necessary to comply with the Water Quality Standards for the Colorado River and Section 303 of the Clean Water Act.

The Bureau of Reclamation (Reclamation) Program Manager serves as staff for the Council. In addition, the permanent Work Group of the Colorado River Basin Salinity Control Forum continues to serve the Council and the Forum in the capacity of a technical review and study team. The Council is further assisted by the Forum's Executive Director.

The Council met in Palm Desert, California, on October 22, 1996. At that meeting, the Council received reports from and made inquiries of the federal agencies involved in salinity control, and approved the budget recommendations contained in this report. The Council also made time available for public comment and one member of the public responded. The record was left open to allow written comment by the public but no comments were received.

COUNCIL COMMENTS AND RECOMMENDATIONS

The 1996 Review, Water Quality Standards for Salinity - Colorado River System Final Report, (1996 Review) June 1996, and Supplemental Report, October, 1996 prepared by the Forum describe the numeric criteria for salinity, the implementation plan, the individual salinity control projects and their status. The Council appreciates the assistance each of the federal agencies provided to the Forum during the preparation of the 1996 Review.

These are uncertain times for the Salinity Control Program. Reclamation is implementing its new basin-wide program, the Department of Agriculture's on-farm program has been incorporated into the new and much larger Environmental Quality Incentives Program, and the Bureau of Land Management continues to develop methods for quantifying salinity reduction benefits within its existing land management programs. The Council urges the federal agencies to continue to consult with the Forum and Work Group with regard to program changes, program evaluations, and program implementation schedules. The Council also requests that as organizational changes occur within the agencies, each agency identify where the responsibility for salinity control lies, and that this information be made available to the Forum's Executive Director at the earliest possible date.

The Council subscribes to the implementation plan described in the 1996 Review. However, because of the uncertainties created by the changes occurring in the federal programs, the Council is concerned that insufficient funding will cause delays in the implementation of salinity control reduction measures as described in the 1996 Review with the resulting impact of exceeding the numeric criteria in the future. It is imperative that the federal agencies vigorously pursue adequate funding for salinity control projects, including appropriate funding for the operation and maintenance of completed projects, in the Administration's budget request each year and encourage Congress to appropriate the funds necessary to carry out the salinity control activities set forth in the 1996 Review in a timely manner.

Bureau of Reclamation

On July 28, 1995, Reclamation's Salinity Control Program was amended by the signing of Public Law 104-20. Under this new authority, Reclamation no longer develops and implements its own salinity control projects but requests proposals from other entities for salinity control projects. Reclamation then evaluates proposals, selects appropriate projects and provides a portion of the funds for implementation. The Council appreciates Reclamation's willingness to include members of the Forum's Work Group on the committee that evaluates and selects the projects to be funded and implemented. The Council feels this enhances the cooperative relationship between Reclamation, the Forum and the Council.

The Council is pleased that the current Administration continues to financially support Reclamation's basin-wide salinity control program and hopes this support will recognize the importance of including sufficient funding to operate and maintain completed projects.

The Council encourages Reclamation to reassert its role as lead federal agency and reconvene the federal work group to provide a forum for discussing and evaluating the direction and rate of implementation of the federal program.

Bureau of Land Management

The Council continues to see organizational and personnel changes in the Bureau of Land Management (BLM). The Council is pleased with the efforts of the BLM to identify activities on public lands which can reduce the salt load in the Colorado River and for attempting to develop methodologies for quantifying those reductions. The initial results of these efforts were demonstrated by the discussions provided by the BLM for the 1996 Review. The Council urges the BLM to continue to seek funding for salt reduction projects administered solely by BLM or in cooperation with state and other federal agencies. The Council recommends that the BLM continue developing, in cooperation with the Forum's Work Group, a program which will allow the tracking of salt load reductions and funding (as funding is programmatic in nature). The Council also encourages the BLM to continue its efforts to identify and plug flowing saline wells.

U.S. Geological Survey

The USGS plays a significant role in fulfilling the federal obligation to assess the progress and effectiveness of the Salinity Control Program. The Council is concerned that information may become less available due to organizational, personnel, and budget changes. The Council urges that continued operation of existing long-term water quality and quantity monitoring stations within the Colorado River Basin be given the highest priority.

Department of Agriculture

In the past, the Department of Agriculture's on-farm program has had some of the most cost effective salinity control projects. The plan of implementation identified in the 1996 Review recently adopted by the Forum places considerable reliance upon the continuation of the USDA program. The Council is concerned that by including the USDA's salinity control program in the much broader Environmental Quality Incentives Program, USDA's commitment to its Colorado River salinity control efforts will be diluted. Because of this concern and the importance of the salinity control program to the entire Colorado River Basin, the Council strongly recommends that the Colorado River Basin be designated a **national priority area** and that as a **national priority area** sufficient funding be provided to maintain USDA's efforts in the Colorado River Basin Salinity Control Program as described in the 1996 Review. Because technical assistance, education, and monitoring and evaluation are critical to the success of USDA's program, the Council recommends that funding for these activities be provided in addition to the funds for cost sharing made available under the EQIP.

The Council is also concerned with the organizational structure USDA has created for administering EQIP. The Council fears that lack of coordination within USDA regional, state and local offices could lead to expenditures of funds for the implementation of less cost effective projects because the distribution of funds is likely to be based on local priorities within each state rather than basin-wide priorities. The necessary coordination could be achieved by the designation of a **national priority area** and then assigning one regional or state office primacy in determining the priority of projects basin-wide. That designated regional or state office could then be the focal point for coordination and consultation with the Council and the Forum. The Council believes that this approach is essential to maintaining a large-scale salinity control program that bases implementation decisions on cost effectiveness.

MANAGEMENT AND BUDGET RECOMMENDATIONS

The Council's budget recommendations represent the minimum funding required for the program to be successful in maintaining salinity within the federally-mandated and state-adopted numeric criteria. The funding levels are consistent with and support the conclusions regarding the funding required to accomplish the plan of implementation recently adopted by the Forum in its 1996 Review. Unlike many other federal programs, the salinity program provides a significant amount of non-federal cost sharing. The states provide 25-30 percent cost share from the Upper Basin Fund and Lower Basin Development Fund. In addition to the states' cost share, the local participating farmers cost share in the USDA on-farm program. The non-federal participants (the states, land owners, irrigation districts, etc.) stand ready in FY 98 to contribute their share of the program costs as an up-front payment. The Council urges the federal agencies to vigorously pursue adequate funding so as to allow timely, continual implementation of the salinity program in a vigorous and cost-effective manner. The agencies' funding requests should be in accordance with Executive Order 12088, which directs the head of each executive agency to take all necessary actions for the prevention, control and abatement of environmental pollution with respect to federal facilities and activities under the control of the agency.

Table 1 contains the Council's recommendations for the federal cost share for FY 98 and FY 99. These funds are for the construction activities necessary to meet the program objectives. The Council will forward these recommendations to the Congress and will seek their support for maintaining adequate funding for the Colorado River Basin Salinity Control Program. The Council wishes to emphasize that any shortfall in these funding levels will have to be offset by increased funding in subsequent years. In addition, delays in the funding of the salinity control program will result in much larger total federal expenditures to achieve and maintain the water quality objectives for the Colorado River.

Again, it should be noted that the funding recommendations contained in Table 1 are for project implementation only. The Council urges the agencies to provide adequate funding to support the operation and maintenance, technical and education assistance, and monitoring and evaluation of implemented projects. The Council recommends that funds for these activities be provided in addition to the funds recommended in Table 1.

Table 1

FUNDING RECOMMENDATIONS

	Fiscal Years	
	1998	1999
DEPARTMENT OF THE INTERIOR		
Bureau of Reclamation [1]	$16,800,000	$17,500,000
Bureau of Land Management [2]	$4,500,000	$5,200,000
DEPARTMENT OF AGRICULTURE [3]	$11,000,000	$12,000,000
TOTAL FUNDS NEEDED	$32,300,000	$34,700,000

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1 The Council anticipates that Reclamation will also budget sufficient funds for required operation and maintenance of constructed units and for plan formulation.

2 The Council anticipates that the BLM will also budget sufficient funds for inventory and ranking, planning, maintenance, monitoring and support.

3 The Council anticipates that Agriculture will also budget sufficient funds for administration, technical assistance, education and monitoring and evaluation.

CONCLUSION

The Council recognizes and appreciates its responsibility for submitting to the federal agencies comments and recommendations on salinity control activities. The Council is generally pleased with the interagency efforts put forth in FY 1996 and looks forward to further success in the coming year. The Council wishes to thank the federal agencies for their written responses to last year's report. The Council requests that written responses to this year's report be provided prior to the October 1997 Advisory Council meeting so that the Forum and the Federal agencies can cooperatively continue to expeditiously carry out the program.

Attachment A

ADVISORY COUNCIL MEMBERSHIP

ARIZONA

Timothy J. Henley
Department of Water Resources
Phoenix, Arizona

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Environmental Program Mgr.
Department of
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Phoenix, Arizona

George W. Barr
Central Arizona Water
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State Engineer
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Gary Beach, Administrator
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Cheyenne, Wyoming

12,002

STATE OF CALIFORNIA—THE RESOURCES AGENCY PETE WILSON, *Governor*

COLORADO RIVER BOARD OF CALIFORNIA
770 FAIRMONT AVENUE, SUITE 100
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October 18, 1996

Mr. Robert A. McCullough
Manager, Planning & Engineering
Imperial Irrigation District
P.O. Box 937
Imperial, CA 92251

Dear Mr. McCullough:

Attached is a copy of the 1995 Annual Report on the Colorado River Basin Salinity Control Program, January 1996, prepared by the Colorado River Basin Salinity Control Advisory Council. The report presents the Advisory Council's recommendations to the federal agencies involved in salinity control activities on appropriate means of controlling the Colorado River's salinity.

If you have any questions, please call me or my staff, Jay Chen, at (818) 543-4676, Extension 303.

Sincerely,

Gerald R. Zimmerman

Gerald R. Zimmerman
Executive Director and
California Member of Colorado
River Basin Salinity Control
Forum, and Advisory Council

Attachment

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1995 ANNUAL REPORT ON THE COLORADO RIVER BASIN SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN SALINITY CONTROL ADVISORY COUNCIL

January 1996

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1995 ANNUAL REPORT
ON THE
COLORADO RIVER BASIN
SALINITY CONTROL PROGRAM

COLORADO RIVER BASIN
SALINITY CONTROL ADVISORY COUNCIL

January 1996

BACKGROUND

Public Law 93-320, also known as the "Colorado River Basin Salinity Control Act of 1974" (Act), authorized the construction, operation, and maintenance of works in the Colorado River Basin to control the salinity of Colorado River water available for use in the United States and Mexico. Section 204 of the Act established the Colorado River Basin Salinity Control Advisory Council (Council). A charter for the Council was originally approved by the Secretaries of the Departments of the Interior and Agriculture and the Administrator of the Environmental Protection Agency (EPA) on February 6, 1976. It was revised on June 22, 1976, and has been renewed biennially. The Council receives reports from the federal agencies involved in salinity control activities and makes recommendations to them regarding appropriate methods for controlling the salinity of the Colorado River in this annual report.

The Council is comprised of up to three members from each of the seven Colorado River Basin states. Representatives are appointed by Governors and current membership is shown on Attachment A. William J. Miller, New Mexico, acts as Chairman of the Council and Gerald R. Zimmerman, California, serves as Vice Chairman. Advisory Council members are, for the most part, also members of the Colorado River Basin Salinity Control Forum (Forum). The Forum is an organization created in 1974 by the seven Colorado River Basin states which was established for the purpose of interstate cooperation and to provide the states with the information necessary to comply with the Water Quality Standards for the Colorado River and Section 303 of the Clean Water Act. The Governors of the seven states also appoint Forum members.

The Bureau of Reclamation (Reclamation) Salinity Coordinator serves as staff for the Council. In addition, the permanent Work Group of the Colorado River Basin Salinity Control Forum continues to serve the Council and the Forum in the capacity of a technical review and study team. The Council is further assisted by the Forum's Executive Director.

The Council met in Lake Havasu City, Arizona, on October 18, 1995. At that meeting, the Council received reports from and made inquiries of the federal agencies involved in salinity control, and approved the budget recommendations contained in this report. The Council also made time available for public comment and one member of the public responded. The record was left open to allow written comment by the public, to date no comments have been received.

COUNCIL COMMENTS AND RECOMMENDATIONS

The 1993 Review, Water Quality Standards for Salinity - Colorado River System Final Report, (1993 Review) October 1993, prepared by the Forum, describes the numeric criteria for salinity, the implementation plan, the individual salinity control projects and their status. The approval of the 1993 Review has taken longer than expected due to the inclusion of Endangered Species Act Section 7 consultation as part of the Environmental Protection Agency (EPA) approval. The next Review will be prepared in 1996 and the Work Group will coordinate its drafting with EPA and the Fish & Wildlife Service in hopes of facilitating their review.

The Council believes that the federal agencies have done an exemplary job coordinating and developing the implementation plan. The Council urges them to continue to consult with the Forum and Work Group with regard to proposed program changes, program evaluations, and implementation schedule revisions for salinity control projects. The Council also requests that the federal agencies identify where agency responsibility for salinity control currently lies, and that this information be presented to the Forum's Executive Director at the earliest possible date. The Council subscribes to the implementation plan described in the 1993 Review. However, insufficient funding levels have caused delays in implementation of salinity control projects in the plan which could result in exceedence of the numeric criteria. It is imperative that the federal agencies vigorously pursue adequate funding for salinity control projects in the administration's budget request each year and encourage Congress to appropriate the funds necessary to carry out the salinity control activities set forth in the 1993 Review in a timely manner.

Bureau of Reclamation

On July, 28 of 1995, Reclamation's Salinity Control Program was amended by the signing of Public Law 104-20. The Council supported this legislation. However, there is now concern that implementation of the program as it is currently envisioned by Reclamation may degrade the existing relationship between Reclamation and the Council. An example of this change is the fact that the draft report to be submitted to Congress, as required under the new law, was reviewed by the Council and the Forum, but ultimately will be submitted without Council or Forum endorsement. In the past, Reclamation would have sought such an endorsement prior to submitting the report.

The Council is pleased that the current administration continues to financially support Reclamation's basinwide salinity control program. This insures that Reclamation's projects will not be severely delayed by funding issues, nor will those portions of multi-agency projects which are Reclamation's responsibility. The Council recognizes Reclamation's accomplishments, most notably those in the Lower Gunnison Basin, Grand Valley, and Paradox Valley Units.

Bureau of Land Management

There has been significant organizational and personnel change in the Bureau of Land Management (BLM) and the salinity control program is now the responsibility of the newly formed National Applied Resource Sciences Center. The Council urges the BLM to continue its efforts to identify activities on public lands which can reduce salt loading of the Colorado River system and to continue to seek funding for salt reduction projects administered solely by BLM or in cooperation with state and other federal agencies.

The Council supports timely implementation of salt reduction projects; however due to lack of appropriate line item funding this has been difficult. The Council remains concerned that tracking of funding and expenditures and identification and quantification of salinity control measures will continue to be difficult due to the watershed management concept of land management utilized by the BLM that does not specifically recognize the impact of activities and projects on the salinity of ground and surface water originating on or flowing from BLM administered lands. The Council recommends that the BLM incorporate in its ecosystem land planning activities the evaluation and reduction of salt discharges into the Colorado River system. The Council recommends that the BLM continue developing salt budget accounting fund identification programs developed in cooperation with the Forum's Work Group and proceed with efforts to identify and plug flowing saline wells.

U.S. Geological Survey

The Council is pleased that the current administration continues to support the U.S. Geological Survey (USGS) program as it is a federal obligation to provide the water quality and hydrologic data collection and interpretive studies necessary to meet the objectives of and enable assessment of the progress of the salinity control program. The Council recognizes that the USGS plays a commendable role in fulfilling this federal obligation. However, there is concern that information may become less available due to organizational, personnel, and budget changes. The Council urges that continued operation of existing long-term water quality and quantity monitoring stations be given the highest priority to enable the USGS to continue providing essential salinity data and interpretive analyses.

The Council requests that consultation be undertaken with the Forum and its Work Group prior to any plans to downsize the network of water quality and quantity stations that are necessary for the (1) interpretation of the effectiveness of specific salinity control projects and activities and (2) determination of unidentified salinity control opportunities. The Council is concerned that current USGS plans to further downgrade the number of NASQAN stations, and others, will severely impact opportunities to evaluate and improve the salinity control program and may inhibit future investigative efforts by disrupting long term records of water quantity and quality at key stations. The Council urges USGS to pursue funding to maintain its essential, traditional program of basic water quantity and quality data collection.

Department of Agriculture

Administration of the salinity control program was consolidated within the Natural Resources Conservation Service (NRCS) and program management activities were coordinated out of the Washington, D.C. office due to reorganization within the agency. The Council reiterates its past recommendation that the U.S. Department of Agriculture (USDA) consider transferring primacy in the day-to-day salinity control responsibility to one of the Upper Colorado River Basin state or regional offices to provide more effective and accessible coordination and facilitation.

The Council recognizes that some of the most cost effective projects in the plan of implementation adopted by the states in the water quality standards for salinity control have been a result of USDA's on-farm salinity control program. Also, the Council recognizes the importance of a basin-wide approach to determining the implementation of the most cost effective measures to control salinity in the waters of the Colorado River. The Council fears that lack of coordination within USDA regional or state offices could lead to expenditure of funds for the implementation of less cost effective projects because the distribution of funds could be based on regional or state priorities rather than basin-wide priorities. The necessary coordination of USDA's salinity control activities could be accomplished by assigning one regional or state office primacy in determining the priority of projects basin-wide. That designated state or regional office could then be the focal point for coordination and consultation with the Council and the Colorado River Basin Salinity Control Forum. The Council recommends that the USDA, through NRCS, strive to ensure that the most cost effective projects basin-wide are implemented and adequately funded to meet water quality objectives of P.L. 93-320.

Funding for the Cooperative Research, Extension and Education Service (CREES) is administered by NRCS. The CREES provides educational services and facilitates information transfer, which are two functions important to the success of the USDA salinity control program. The Council recognizes the important role of CREES and recommends that NRCS adequately fund CREES activities to support salinity control education and project implementation at the local level.

There has been concern over lack of adequate funding being requested and uncertainty within the agency regarding the future of the salinity control program due to the Agriculture Reconciliation Bill that is presently in the House and Senate. If passed, this bill could substantially impact the USDA salinity program by consolidating all agency conservation programs into a single large program. The Council is concerned that if the bill is passed as presently worded it may become extremely difficult to track and support funding for salinity control activities due to the elimination of specific line item appropriations for salt reduction projects.

The USDA program has played a major role in the implementation of cost-effective salinity control projects and will continue to be important to the success of the program. The on-farm program has been one of the most cost-effective components of the basinwide program and the Council recommends that the NRCS strive to insure that this component is not jeopardized.

There has been continued effort to resolve issues that arise between the USDA and the U.S. Fish and Wildlife Service regarding wetlands mitigation. The Council recognizes that progress is being made and supports the idea that both agencies are adopting more flexible policies that can minimize or resolve these issues. The Council recommends NRCS incorporate a wildlife replacement section in the National Handbook for the Colorado Salinity Control Program.

In summary, it is important to emphasize the USDA's role in preventing and controlling pollution. Under the Plan of Implementation in the 1993 Review, 58% of the projected salt removal will be accomplished by the USDA program and accordingly, recognition of the USDA's statutory role in maintaining the Colorado River water quality standards and their associated numeric criteria is essential.

MANAGEMENT AND BUDGET RECOMMENDATIONS

The Council's budget recommendations represent the minimum funding required for the program to be successful in maintaining salinity within the federally-mandated and state-adopted numeric criteria. All activities are consistent with the salinity control program set forth in the "1993 Review-Water Quality Standards for Salinity-Colorado River System Final Report." Unlike many other federal programs, the salinity program provides a significant amount of non-federal cost sharing (25-30 percent from the Upper Basin Fund and Lower Basin Development Fund) and an additional 30 percent of up-front cost share from the local participating farmers for the USDA onfarm program. The non-federal participants (land owners, irrigation districts, etc.) stand ready to contribute their up-front share of program costs and the Basin Funds are capable of reimbursing their appropriate share as the costs are incurred. The Council urges the federal agencies to vigorously pursue adequate funding so as to allow timely, continual implementation of the salinity program in a vigorous and cost-effective manner. The agencies funding requests should be in accordance with Executive Order 12088, which directs the head of each executive agency to take all necessary actions for the prevention, control and abatement of environmental pollution with respect to federal facilities and activities under the control of the agency.

Table 1 contains the Council's recommendations for Congressional appropriations for FY 1997 and FY 1998. The Council hastens to point out that any shortfall in these funding levels will likely have to be offset by increased funding in subsequent years. In addition, delays in the funding of the salinity control program will result in much larger total federal expenditures to achieve and maintain the water quality standards for the Colorado River.

Table 1

FUNDING RECOMMENDATIONS

	Fiscal Years	
	1997	1998
DEPARTMENT OF THE INTERIOR		
Bureau of Reclamation [1]	$11,500,000	$11,500,000
(Original Program)	($5,500,000)	($5,300,000)
(1995 Authority)	($6,000,000)	($6,200,000)
Bureau of Land Management [2]	$3,700,000	$3,700,000
DEPARTMENT OF AGRICULTURE [3]	$9,800,000	$9,800,000
TOTAL FUNDS NEEDED	$25,000,000	$25,000,000

1 The Council anticipates that Reclamation will also budget sufficient funds for required operation and maintenance of constructed units and for plan formulation.

2 This line item identifies funds needed for improvements on BLM managed lands and includes $800,000 that is to be appropriated directly for salinity control for salinity activities. The Council anticipates that the BLM will also budget sufficient funds for inventory and ranking, planning, maintenance, monitoring and support.

3 The Council anticipates that Agriculture will also budget sufficient funds for administration, technical information and education.

CONCLUSION

The Council recognizes and appreciates its responsibility for submitting to the federal agencies comments and recommendations on salinity control activities. The Council is generally pleased with the interagency efforts put forth in FY 1995, and looks forward to further success in the coming year. The Council wishes to thank the federal agencies for their written responses to last year's report. The Council requests that written responses to this year's report be provided by the next scheduled meeting of the Council, October 22, 1996, so that the Forum and the Federal agencies can cooperatively continue to expeditiously carry out the program.

Attachment A

ADVISORY COUNCIL MEMBERSHIP

ARIZONA

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Phoenix, Arizona

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State Engineer
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Gary Beach, Administrator
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Cheyenne, Wyoming

19-31

Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley

DRAFT FINAL REPORT December 1999

Grant Agreement No. B-80560

02.01003 v01

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WATER DEPARTMENT ROUTING SLIP (SUSPENSE)

SUSPENSED TO		INITIALS	DATE	ACTION CODE	ROUTING/ COMMENTS
MGR	MANAGER, Water				
AM	ASST. MANAGER				
CON	CONSTRUCTION				
RM	RESOURCES MANAGEMENT	Jre	1/12	A	done/L
SPC	SPEC. PROJECTS COORD.	Jre	1/12	A	done/L
WA	WATER ADMIN. SERVICES				
WE	WATER ENGINEERING				
WM	WATER MAINTENANCE				
WO	WATER OPERATIONS				
LEGAL					
Brad Lucky and Don Cox		Jre	1/12	Info. Only	done/L

CODE: A = ACTION C = COORDINATE I = INFO R = RETAIN

SUBJECT: Memo and document from Khaled M. Bali re: Draft Final Report: I&D Management and Surface Runoff Reduction in the Imperial Valley Project

Please note: a 3.5" IBM Formatted diskette w/computer program, Excel spreadsheet and output file is available, if you need. /L

ACTION COMMENTS: Please review and comment if necessary.

Route through Manager, Water for: Signature [ ] Sign-off [x]

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December 31, 1999

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Re: Draft final report, Contract No. B-80560: Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley Project

Attached please find our draft final report for the above project. Please review the attached report and send your comments to us by February 29, 2000. Thank you for your time and attention.

Sincerely,

Khaled Bali

Khaled M. Bali
Farm Advisor
Irrigation/Water Management.

Enc.

C: Steve Jones, USBR
Steve Kenell, IID
Rick Snyder, UCD
Mark Grismer, UCD
Ian Tod, UCD
Juan Guerrero, UCCE
Refugio Gonzalez, UCCE

JAN 10

Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley

DRAFT FINAL REPORT December 1999

Grant Agreement No. B-80560

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DRAFT FOR DISCUSSION ONLY

Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999

Table of Contents

Executive Summary:

Colorado River water is the lifeblood of the Imperial Valley as it is the only source of irrigation and drinking water in the Valley. As much as 2.8-3.0 million acre-feet (MAF) out of an recently agreed upon allotment of 3.1 MAF of Colorado River water are used every year to irrigate more than 500,000 acres of land in the Imperial Valley. Surface and subsurface drainage water from irrigated fields enter the Salton Sea, the drainage sink for the Imperial and Coachella Valleys since its formation in 1905. The Sea continues to exist because of agriculture drainage water from these Valleys as well as agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. Because of drainage and its impact on the Sea, several water quality issues exist in the Imperial Valley in which water conservation plays a role.

This report describes the development of a new method to minimize or eliminate surface runoff (tailwater) from irrigated forage crops grown on heavy clay soils of the Imperial Valley. It also presents the best management practices (BMP's) to achieve the above objective and describes the demonstration project that was conducted at the University of California Desert Research & Extension Center (UCDREC) between 1995 and 1999 to evaluate the effectiveness of this new method.

An alluvial, moderately saline (EC~ 6-8 dS/m in the rootzone) clay soil at UCDREC, Holtville, CA, was cultivated and sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Alfalfa was planted in November 1995 (Field No. 2) followed by a corn planting on the same ground in February 1999. A total of 15 acres were used in this project. The area was divided into 2 fields each containing separate plantings of alfalfa (followed by corn) and sudangrass. Each field contained 4 borders; each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to determine soil moisture, water table elevation and quality, and soil salinity at different depths. Moisture contents at all sampling locations were measured using a neutron probe. Soil moisture measurements were made prior to irrigation and 2 or 3 days after irrigation. Alfalfa and sudangrass hay yields were determined for every cutting.

Significant amount of runoff water was saved as a result of the implementation of this method. Overall only 2% of the applied water became runoff resulting in a significant increase in water application efficiency. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield was not affected by the surface runoff reduction treatment and resulted in similar water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average applied water use efficiencies (AWUE's) of 1.77 tons of sudangrass per ac-ft/ac and 1.76 dry tons of alfalfa per ac-ft/ac. The corresponding WUE (includes AW, rain and WT contributions to ET of the crop) figures for sudangrass and alfalfa were 1.75 and 1.54, respectively. This alfalfa AWUE value (i.e. 1.76) compared more favorably with the CA and AZ statewide (1998) average AWUE's of 1.80 and 1.49 dry tons of alfalfa per ac-ft/ac, respectively,

as compared to the Imperial Valley (1996-1998) average AWUE of 1.17 tons of alfalfa per ac-ft/ac.

We found that shutting off the applied water at when the surface wetting front reached approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border while reducing runoff to only 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. After three years, the average crop coefficient for sudangrass during the entire growing seasons was approximately 0.81.

An increase in soil salinity of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction method.

Additional work is needed to verify the applicability of this method to commercial fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is common in the Imperial Valley.

Preface

The purpose of the Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley Project was to improve irrigation efficiency by reducing surface runoff, utilizing the shallow saline watertable, and determination of crop coefficients for the two common field crops (alfalfa and sudangrass) to increase utilization of CIMIS reference evapotranspiration data for irrigation scheduling in the Valley. The main activity of the project was field trials undertaken to develop and demonstrate a new method of predicting irrigation cutoff time to reduce or eliminate surface runoff.

The report is laid out in two sections. In Section I, the Best Management Practices (BMP) for Irrigation Management and Surface Runoff Reduction from Heavy Clay Soils are presented. The BMP are based on the findings of the field trials. In Section II, the field trials are described in detail and the results are presented and analyzed.

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Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999

SECTION I

Best Management Practices
for
Irrigation Management and Surface Runoff Reduction in Heavy Clay Soils

By

Khaled M. Bali[1], Mark E. Grismer[2], Ian C. Tod[3], Richard L. Snyder[4], & Juan N. Guerrero[1]

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Funded by California Department of Water Resources
Agricultural Drainage Reduction Program, Office of Water Conservation.
Contract No. B-80560

1.1 Introduction:

Colorado River water is the only source of irrigation and drinking water in the Imperial Valley. Approximately 17% of the irrigation water delivered in the Imperial Valley later re-appears as tailwater. Efficient irrigation practices are needed to minimize surface runoff and to reduce the amount of chemicals translocated downstream in runoff water. The Salton Sea water surface elevation has recently reached the highest level on record since 1920. Surface runoff and subsurface drainage water from agricultural lands in Imperial Valley contribute to this increase in Salton Sea elevation. Currently, the salinity of the Sea is over 47,000 ppm, approximately 30% greater than the salinity of the Pacific Ocean.

Issues related to salinity, irrigation management, and water quality are also addressed in this report. The focus of this report is on field crops, specifically alfalfa and sudangrass. In 1998, field crops accounted for almost 80% of the nearly 500,000 acres of irrigated land in the Imperial Valley while heavy clay soils represents more than 60% of the irrigated land. Alfalfa and sudangrass water use account for more than 50% of the total crop water use in the Valley.

This publication summarizes the results of work conducted by the authors at the University of California Desert Research and Extension Center (UCDREC) to develop and demonstrate a simple field procedure to determine the irrigation cutoff time in cracking clay soil so that runoff losses are minimized. This research and demonstration project was conducted at UCDREC to verify the effectiveness of this method and its possible impact on alfalfa and sudangrass production in the Imperial Valley. The Center clay soils are typical of a major portion of the Imperial Valley.

1.2 Objective

The objective of this Handbook is to introduce a simple and a practical method to reduce or eliminate surface runoff from irrigation of heavy clay soils. Such soils represent more than 60% of the nearly 500,000 acres of irrigated land in the Imperial Valley, CA. Approximately 17% of the irrigation water is lost to surface runoff due to the limited infiltration in clay soils. Water penetration is usually limited to free water flow into and through cracks. Grismer and Tod (1994) developed and tested a field procedure to estimate irrigation cut-off time for cracking clay soils using a volume balance method that is applied here.

1.3 Irrigation Cutoff-time method:

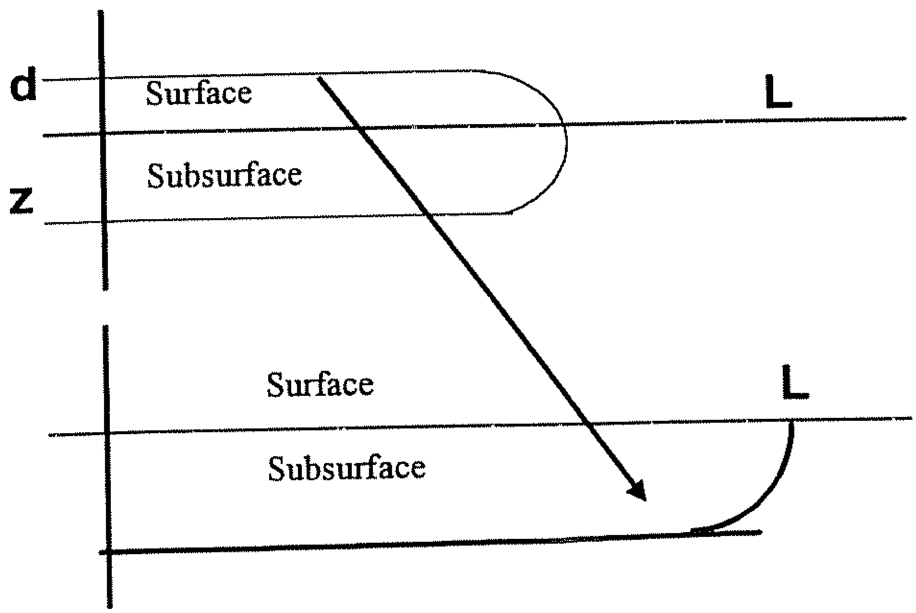
Irrigation scheduling can be based on a relatively simple technique that predicts the cut-off time necessary to minimize runoff and to improve water use efficiency. While the method is applicable for all soils it works best with heavy clay soils. The method is a combination of a volume balance model and a two-point measurement method. When applying the method to clay soils, the main objective is to irrigate using sufficient water to fill soil cracks with little or no runoff. The cut-off time or cut-off distance can be calculated for a given border check layout knowing that the total volume of water applied equals that volume stored on the surface plus that below (subsurface storage).

During an irrigation event, the volume of applied water can be estimated from onflow rate and time since irrigation began. The surface storage is the product of the average depth of water and the area covered by water. Similarly, the volume of the subsurface storage is essentially the volume of soil cracks. The method of Grismer and Tod (1994) can be used to estimate the volume of the cracks and then estimate the amount of water needed to irrigate the field with little or no runoff. Figure 1 schematically illustrates this concept as applicable to border-irrigated heavy clay soils. Variations of this method could be used on other soil types and/or furrow-irrigated fields.

The following parameters are needed to use the cut-off time method to determine the irrigation onflow time necessary to minimize or eliminate runoff:

1- Border width and length (feet).
2- Average onflow rate (cfs).
3- Advance rate (ft/min) **or** one or two points of water advance (ft) with time along the border.

Fig. 1.



We have developed simple graphs and charts that can be used by irrigators to estimate irrigation cut-off time or cut-off distance and the average depth of application. We have also developed an Excel spreadsheet and a stand-alone computer program for farm managers and irrigation personnel who are interested in irrigation evaluation or to customize graphs or charts for particular fields. These additional tools are not designed for or needed by irrigators to use this method in the field. Tables 1-7 can be used to estimate the necessary cut-off times or cut-off distances to eliminate or reduce surface runoff in heavy clay soils. While these tables are designed for borders having ¼-mile runs (approximately 1200-1300 ft runs), they can be adapted for use on ½-mile runs by simply doubling the irrigation time. Onflow rates typically range from 2-3 cfs per 65 ft wide borders at the UCDREC that served as the basis of the Tables and Charts.

Typical water orders for a 40-acre field (36-38 acres of net irrigated area) in the Imperial Valley range from 7-10 cfs (approximately 14-20 ac-ft) such that 2- 4 borders can be irrigated at a time depending on border width. Most fields in the Imperial Valley are on slopes ranging between 0.1 - 0.2% (approximately 1-2 ft drop per 1000 ft of run). The following examples illustrate the use of the Tables and Charts to determine the irrigation cut-off time or cut-off distance necessary to eliminate surface runoff.

1.4 Determination of cutoff-distance:

Based on our experience in heavy clay soils in the Imperial Valley, the cutoff distance for most ¼-mile run borders is between 850 and 1050 ft for wide range of flow rates and field conditions. The cut-off distance can be estimated from simple measurements. The irrigator needs three stakes, watch and a tape measure. The following example illustrates this concept:

For ¼-mile run,

1- Place one stake at 300 ft from the water inlet
2- Place the second stake at 400 ft from the inlet
3- Place the third one at 1000 ft from the inlet
4- Determine the time it takes for the water to advance from the 1st stake to the second one
5- Use Table 2 to estimate the cut-off distance
6- The third stake could be use as a guide to turn the water off as the water approaches the estimated distance

Example 1:

Given a field that has 65 ft x 1200 ft borders, determine the cut-off distance when irrigating in sets of 4 borders and with a water order of approximately 9 cfs (approximately 18 ac-ft in 24 hr period).

- Average flow rate per border = 9 cfs/4 = 2.25 cfs/border
- Determine the time it takes for the water to advance from 1st stake to the 2nd one. For

this example, 26 minutes were required for the surface water to advance between the first and second stake

- Use Table 1 (for an onflow rate of 2.2 cfs) to find the cut-off distance. In this example, we look under the advance time of 26 minutes. The corresponding cut-distance is approximately 970 ft down the border.

1.5 Determination of cut-off time:

Example 2:

Given a field that has 65 ft x 1200 ft borders, determine the cut-off time when irrigating in sets of 4 borders and with a water order of approximately 9 cfs (approximately 18 ac-ft in 24 hr period).

- Average flow rate per border = 9 cfs/4 = 2.25 cfs/border
- Measure the advance rate; that is, the time it takes for the water to advance some distance between 100 and 500 ft along the border. For this example, 40 minutes were required for the surface advance to reach 150 ft from the turnout.
- Compute the advance rate. In this example, 150 ft/40 minutes = 3.75 ft/min.

Use Table 3 (for an onflow rate of 2.2 cfs) to find the cut-off time. In this example, we look under the advance rate column for a value close to 3.75; choosing 3.8, the corresponding cut-off time is approximately 255 minutes or when the water reaches approximately 970 ft down the border. The average depth of application is also given at approximately 5.2 inches.

Example 3:

In the same manner, Fig. 3 can be used to estimate the irrigation cut-off time and average depth of application. Use the information from Example 1 (onflow rate of 2.25 cfs and advance rate of 3.75 ft/min) to estimate the irrigation cut-off time and average depth of application.

- Using Figure 3, draw a vertical line at an advance rate of approximately 3.75 and read the cut-off time that crosses the irrigation cut-off time curve; that is, approximately 260 minutes. Similarly, Figure 3 shows a corresponding average depth of application of approximately 5.25 inches.

1.6 Determination of cutoff time or distance from pre-determined soil moisture depletion

If you know that the average depth of application (or average soil moisture depletion is 5.2 inches) before the irrigation event, you can determine the irrigation cut-off time and distance from Figures 8-13.

Example 4:

Again using the field information from Example 1, determine the cut-off time and distance for a soil moisture depletion level of 5.2 inches.

-Using Figure 9, draw a vertical line at a soil moisture depletion level of 5.2 inches and read the cut-off distance that crosses the irrigation cut-off time curve; that is, the irrigation cut-off time is approximately 255 minutes and the irrigation cut-off distance is approximately 975 ft.

Please note that the information in Tables 1-7 and Figures 2-13 are for borders that are 65 ft wide and 1200 ft long and for a slope of 0.1%.

An Excel spreadsheet can be used to generate tables and figures for various combinations of flow rates, slopes, and border-check dimensions of interest.

Example 5:

Use the information in Example 1 to determine the cut-off time, cut-off distance and average depth of application using the Excel spreadsheet.

- Border width 65 ft, border length 1200 ft, average flow rate 2.25 cfs per border, it took 40 minutes for the water to advance 150 ft.
- Enter the above information into the spreadsheet
- Cutoff time = 260 minutes
- Cutoff distance = 976ft
- Average depth infiltrated = 5.40 inches

1.7 Additional information

For additional information or for customized tables or figures for your field, please feel free to use the enclosed spreadsheet, or contact us at 760-352-9474 or via e-mail at kmbali@ucdavis.edu.

Table 1. Irrigation Cut-off distance for border-irrigated alfalfa field
(Border width 65 ft, border length 1200 ft, slope 0.1%)

Time (min)/100 ft of advance	Estimated cut-off distance (ft)				
	****************** Flow rate (cfs)****************				
	2.0	**2.2**	**2.4**	**2.6**	**2.8**
16				845	855
18	850	865	875	885	895
20	890	890	910	920	925
22	915	925	935	945	950
24	940	950	955	965	970
26	960	970	975	985	990
28	975	985	990	100	1005
30	990	1000	1005	1010	
32	1000	1010	1020		
34	1015	1020			
36	1025	1030			

Table 2. Irrigation Cutoff time for border-irrigated alfalfa field
(Flow rate 2.0 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.0	337	1010	6.23
3.2	312	1000	5.77
3.4	290	985	5.36
3.6	271	975	5.00
3.8	253	960	4.67
4.0	237	950	4.38
4.2	223	935	4.12
4.4	210	925	3.88
4.6	198	910	3.66
4.8	187	900	3.46
5.0	177	885	3.27
5.2	168	875	3.10

Table 3. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.2 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.2	315	1005	6.39
3.4	293	995	5.94
3.6	273	985	5.54
3.8	255	970	5.19
4.0	240	960	4.87
4.2	225	945	4.58
4.4	212	935	4.31
4.6	200	920	4.07
4.8	190	910	3.85
5.0	180	900	3.65
5.2	170	885	3.46
5.4	162	875	3.29

Table 4. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.4 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.4	295	1000	6.53
3.6	275	990	6.09
3.8	257	980	5.70
4.0	242	965	5.35
4.2	227	955	5.04
4.4	214	945	4.75
4.6	203	930	4.49
4.8	192	920	4.25
5.0	182	910	4.03
5.2	172	895	3.82
5.4	164	885	3.63
5.6	156	875	3.46

Table 5. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.6 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.4	296	1010	7.12
3.6	277	995	6.64
3.8	259	985	6.22
4.0	244	975	5.84
4.2	229	965	5.50
4.4	216	950	5.19
4.6	204	940	4.91
4.8	194	930	4.64
5.0	184	920	4.40
5.2	174	905	4.18
5.4	166	895	3.98
5.6	158	884	3.79

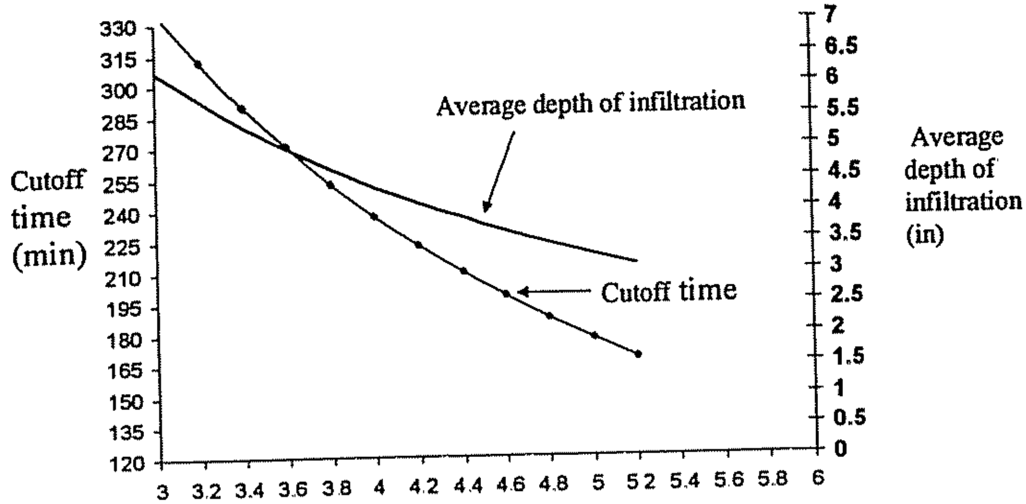
Table 6. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.8 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.8	261	990	6.75
4.0	245	980	6.34
4.2	231	970	5.97
4.4	218	960	5.63
4.6	206	950	5.33
4.8	195	940	5.04
5.0	185	925	4.79
5.2	176	915	4.55
5.4	167	905	4.33
5.6	159	890	4.12
5.8	152	880	3.93
6.0	145	870	3.75

Table 7. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 3.0 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

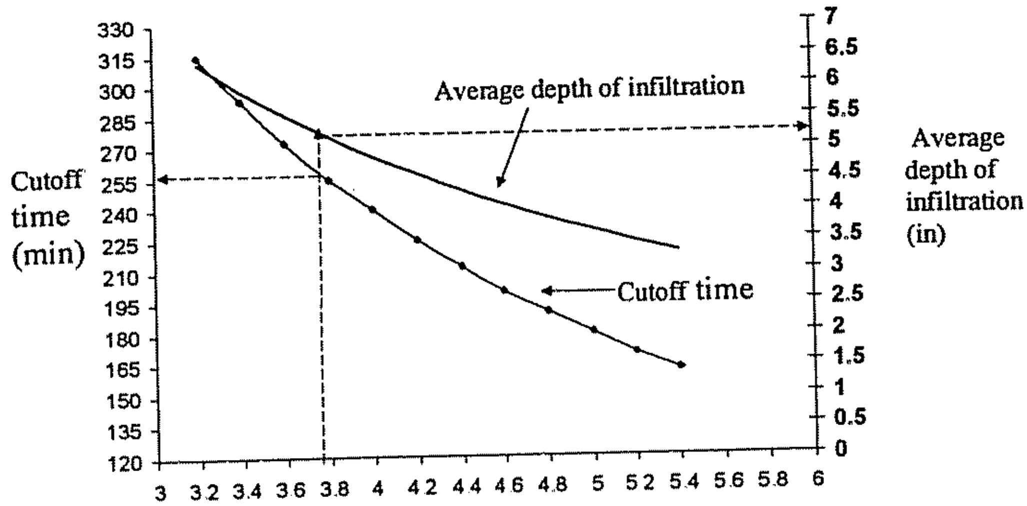
Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
4.0	247	985	6.83
4.2	232	975	6.44
4.4	219	965	6.08
4.6	208	955	5.75
4.8	197	945	5.45
5.0	187	935	5.17
5.2	177	925	4.91
5.4	169	910	4.68
5.6	161	900	4.46
5.8	154	890	4.25
6.0	147	880	4.06
6.2	140	870	3.88

Figure 2. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.0 cfs



Advance distance (ft)/min of irrigation time

Figure 3. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.2 cfs



Advance distance (ft)/min of irrigation time

Figure 4. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.4 cfs

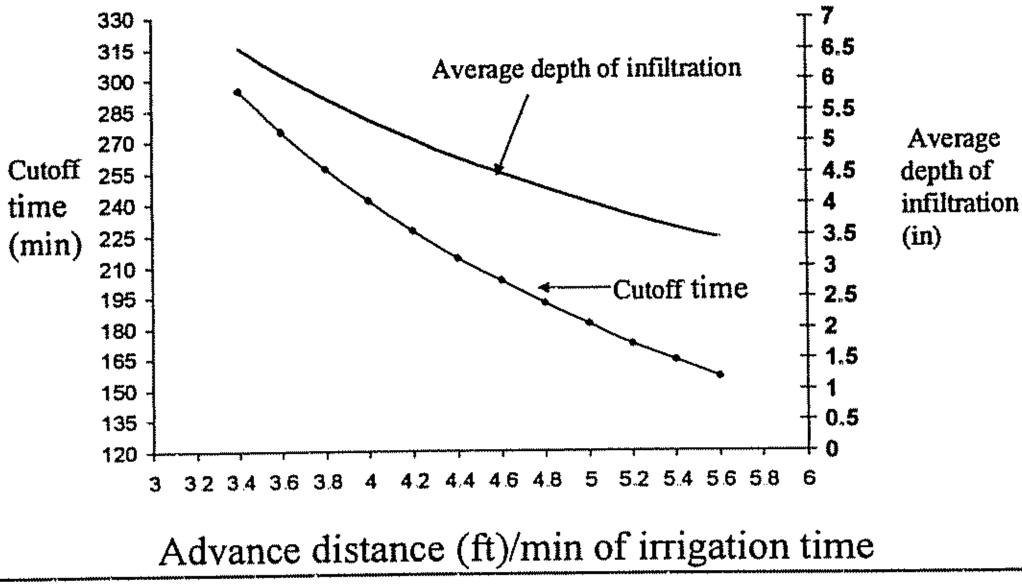
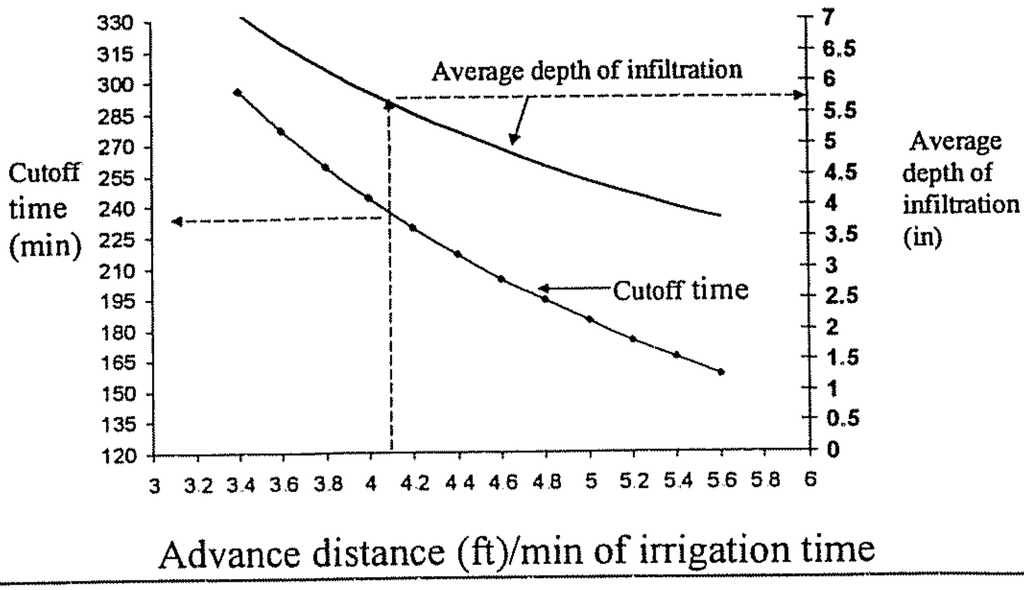


Figure 5. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.6 cfs



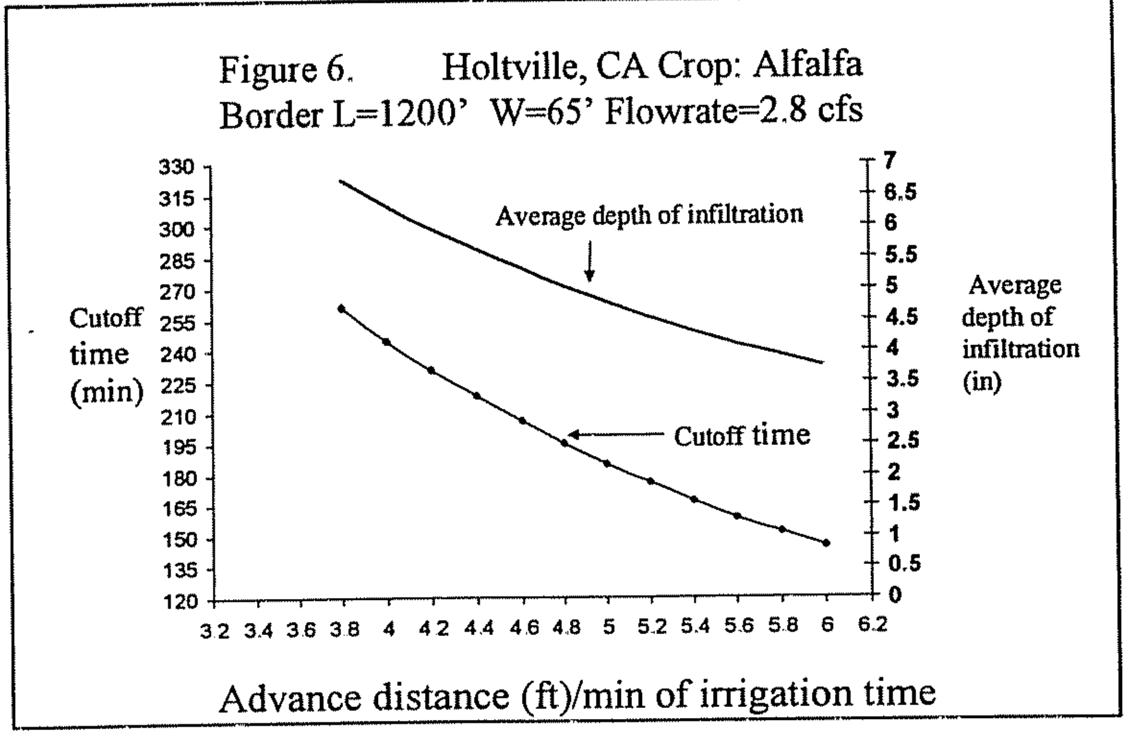


Figure 6. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.8 cfs
Cutoff time (min)
330
315
300
285
270
255
240
225
210
195
180
165
150
135
120
Average depth of infiltration
Cutoff time
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Average depth of infiltration (in)
3.2 3.4 3.6 3.8 4 4.2 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8 6 6.2
Advance distance (ft)/min of irrigation time

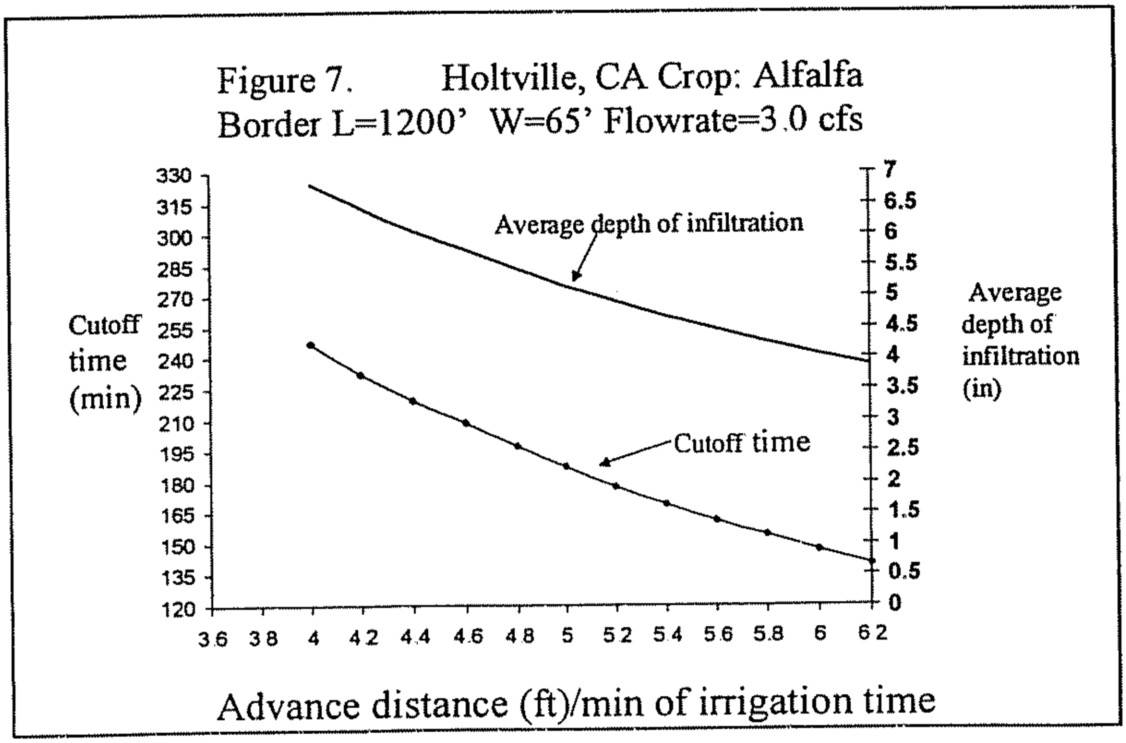
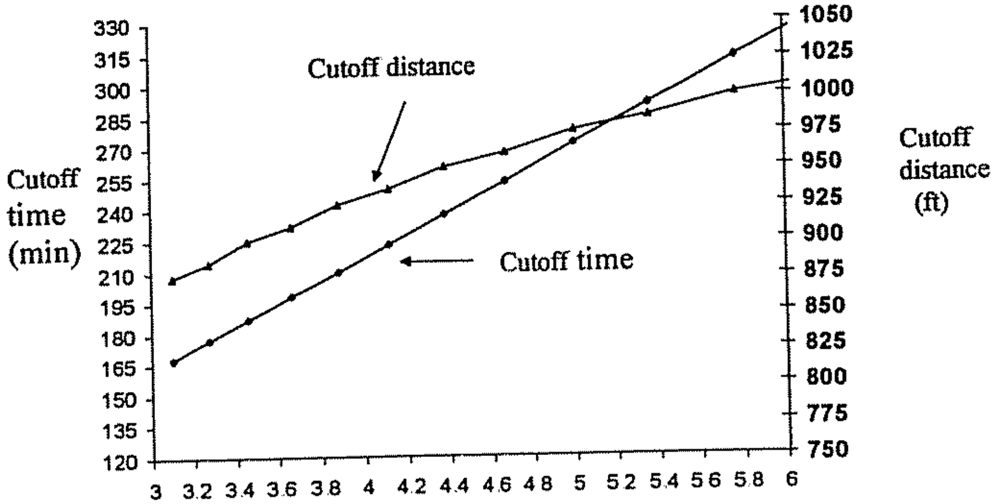


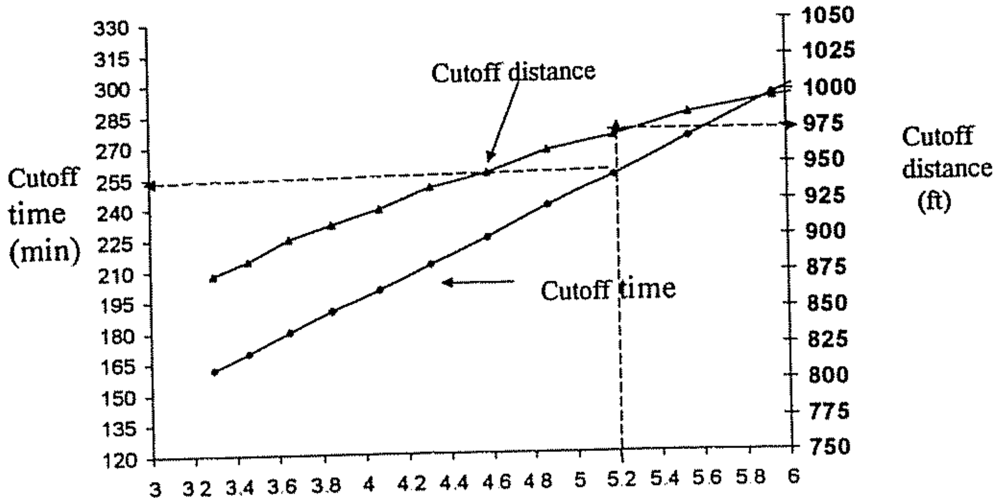
Figure 7. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=3.0 cfs
Cutoff time (min)
330
315
300
285
270
255
240
225
210
195
180
165
150
135
120
Average depth of infiltration
Cutoff time
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Average depth of infiltration (in)
3.6 3.8 4 4.2 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8 6 6.2
Advance distance (ft)/min of irrigation time

Figure 8. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.0 cfs



Soil moisture depletion (in)

Figure 9. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.2 cfs



Soil moisture depletion (in)

Figure 10. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.4 cfs

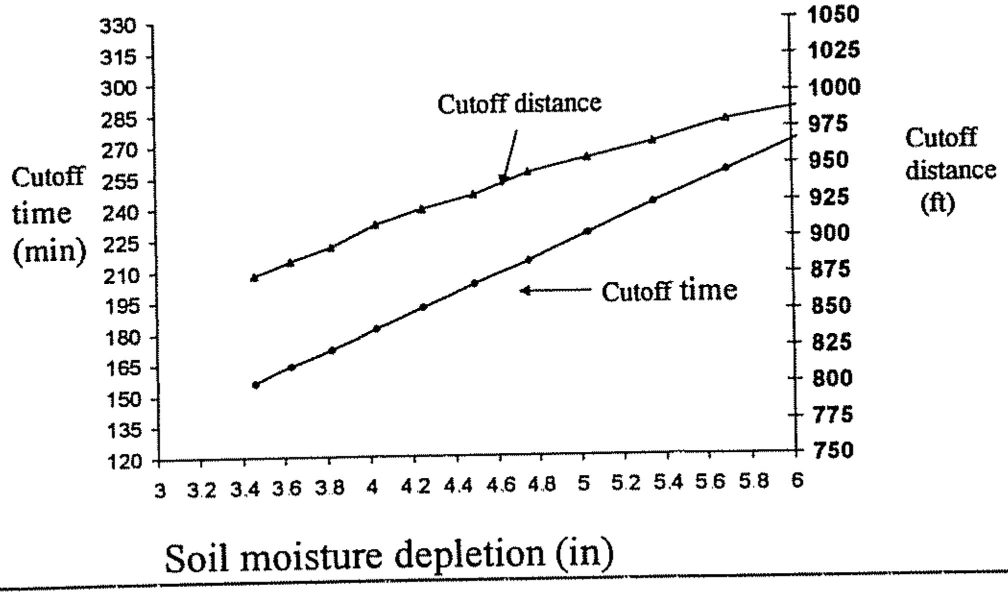


Figure 11. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.6 cfs

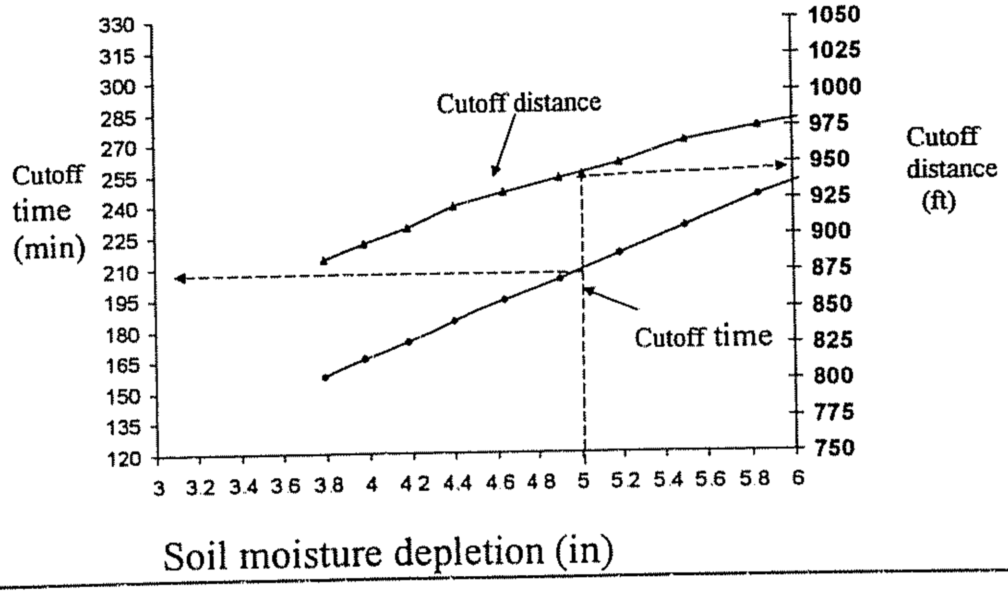


Figure 12. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.8 cfs

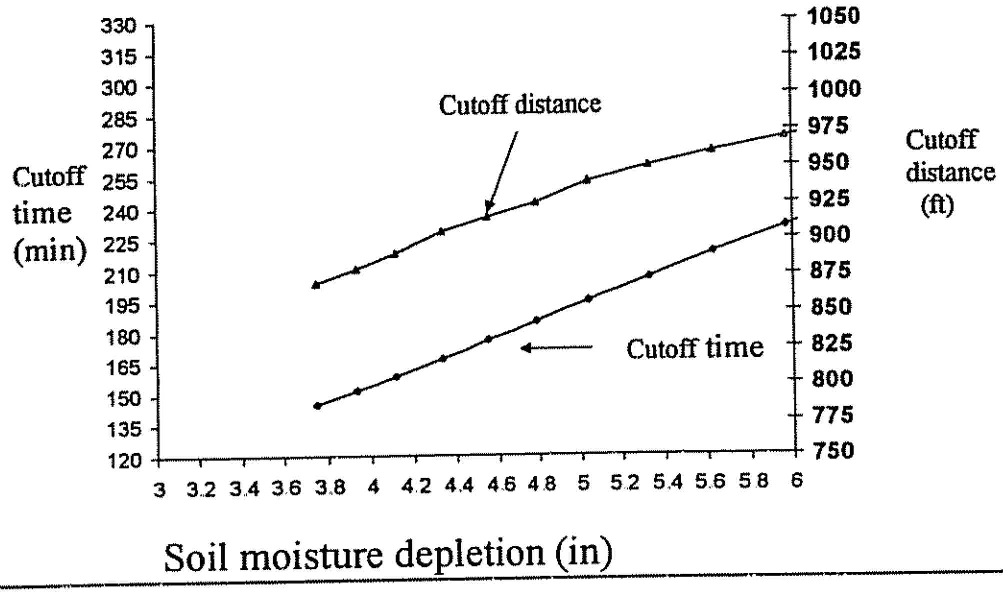
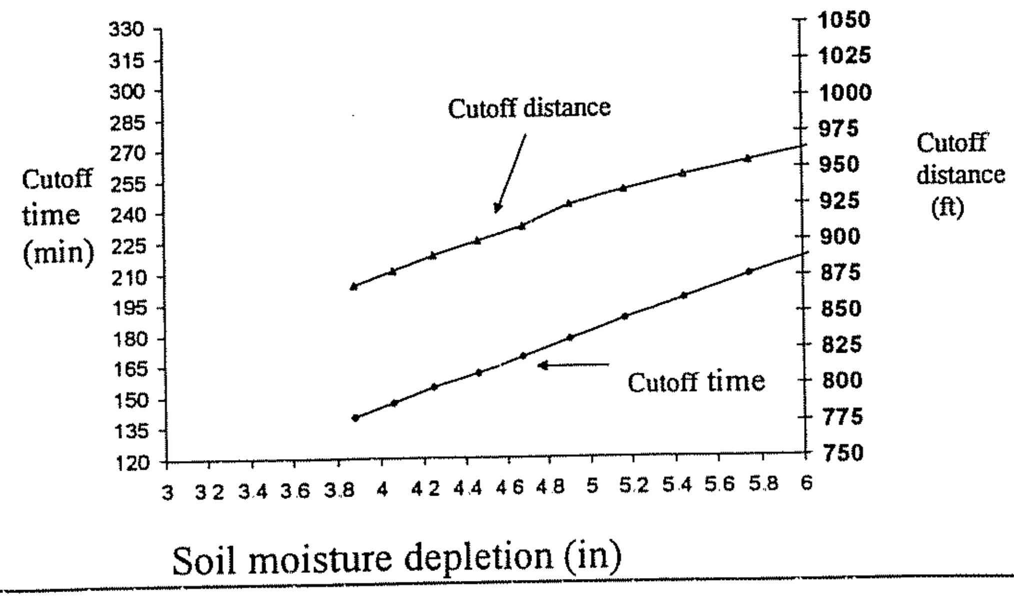


Figure 13. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=3.0 cfs



1.8 Determination of heavy clay soil water-holding characteristics.

Soil-water holding characteristics can best be determined from soil cores taken from the field, but useful estimates can often be made from data available in soil survey reports. Estimated field capacity and available water capacity reported here are based on data from USDA Soil Conservation Service (NRCS) soil survey reports.

Table 8. Soil water-holding characteristics of Imperial County heavy clay soils.

			Available Water (in/in) *Depth (inches)*			Field Capacity (in/in) *Depth (inches)*		
Series	Symbols	Maximum Depth (in)	0-24	24-48	48+	0-24	24-48	48+
Glenbar	105, 106, 115, 116	60	0.20	0.20	0.20	0.39	0.39	0.39
Imperial	111, 112, 114	60	0.21	0.21	0.21	0.42	0.42	0.42

* Water-holding Characteristics of California Soils- University of California-DANR Leaflet 21463

1.9 Computer program

The attached IBM formatted diskette contains a user-friendly computer program that considers practical applications of the runoff reduction method described above. The program includes educational elements about water quality and soil salinity as well as practical applications of surface runoff reduction method. To run the program:

- Windows 95/98, just double click on the SRRP2.EXE file and then follow instructions on the screen
- DOS: at the DOS command, just type **SRRP2.EXE** and then follow instructions on the screen

The computer program is a stand-alone application and does not require any other application/software. The disk also contains sample output files.

References:

Grismer, M. E. And I. C. Tod. 1994. Field evaluation helps calculate irrigation time for cracking clay soils. Cal. A. 48(4):33-36.

Water-holding Characteristics of California Soils- University of California-DANR Leaflet 21463.

Appendix 1: Excel Spreadsheet

File: Coftime3
Irrigation Date:
Field ID:
Border or set No:
Field Characteristics:

Border length (ft)	L=	1200	
Border width (ft)	W=	65	
Field slope (ft/ft)	S=	0.001	
Surface roughness & crop maturity	n=	0.031	
(n=.014-.017 for newly planted crop)			
(n=0.017-.031 for mature crop)			

Measurements:

			Advance ratio (ft/min)
Flowrate (cfs):	Q=	**2.25**	
Advance time (min)	t=	**40**	3.8
Advance distance (ft)	Lx=	**150**	

****
** Estimated average depth of infiltration: **5.40** inches **
**
** Estimated cutoff time: **260** minutes **
** Estimated cutoff distance: **976** ft **
****

APPENDIX 2

Sample output of SRRP2.

```
File Name: output
 Crop: Alfalfa
 Irrigation Management & Surface Runoff Reduction Program
 SRRP ver. 1.0  APR. 1997  K. M. Bali, UCCE
 Copyright (c) 1997, Version 1.00  DRAFT

 ----------------------------------------
 Border length (ft):     1200
 Border width (ft):        65
 Field slope (ft/ft):    .0010
 Crop maturity factor:    .0310
 Flow rate per border in cfs:  2.250
 Advance distance in ft:    150
 Advance time in minutes:    40.
 Desired application depth (in):   5.00
 -----------------------------
 Infiltrated water depth:   5.40 inches
 Estimated cutoff time to reduce or eliminate
 surface runoff:    260. minutes

 Irrigating time    App. Eff.    Deep Perc.   Runoff
 --(minutes)----   -------------(%)--------------
        260.          92.5         7.5           .0
        270.          89.1         7.2          3.7
        280.          85.9         6.9          7.1
        290.          83.0         6.7         10.3
        300.          80.2         6.5         13.3
        310.          77.6         6.3         16.1
        320.          75.2         6.1         18.7
        330.          72.9         5.9         21.2
```

Appendix 3:

Surface Irrigation Cutoff Time Calculations

Field Identification:__________________ Date:________________________

Border Number: __________________

Field Characteristics:

Surface Roughness (n)	
newly planted	$0.014 \leq n \leq 0.017$
crop near maturity	$0.023 \leq n \leq 0.031$

Border length (ft) L = __________
Border width (ft) w = __________
Field slope (%) s = __________
Crop & maturity n = __________

Measurements:
Onflow rate (cfs) Q = __________
Advance time (min) t = __________
Advance dist. (ft) Lx = __________

{These measurements are taken when the surface wetting front has advanced 1/4 to 1/3 of the border length down the field.}

Flow depth (ft) d $=[Q*n/(1.486*w*\sqrt{s})]^{0.6}$ = ____________

Total volume applied (ft3) TAW = Q*t*60 = ____________
Surface water volume (ft3) SW = Lx*w*d = ____________
Infiltrated (crack) water volume (ft3) IW =TAW-SW = ____________

Infiltrated water depth (ft) z = IW/(Lx*W)= ____________

Cutoff time (min) L*W*Z/(Q*60) = ____________

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Section II: Summary of Field trials

Section II
Summary of Field Trials

1.1 Executive summary

Colorado River water is the lifeblood of the Imperial Valley as it is the only source of irrigation and drinking water in the Valley. As much as 2.8-3.0 million acre-feet (MAF) out of a recently agreed upon allotment of 3.1 MAF of Colorado River water are used every year to irrigate more than 500,000 acres of land in the Imperial Valley. Surface and subsurface drainage water from irrigated fields enter the Salton Sea, the drainage sink for the Imperial and Coachella Valleys since its formation in 1905. The Sea continues to exist because of agriculture drainage water from these Valleys as well as agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. Because of drainage and its impact on the Sea, several water quality issues exist in the Imperial Valley in which water conservation plays a role.

This report describes the development of a new method to minimize or eliminate surface runoff (tailwater) from irrigated forage crops grown on heavy clay soils of the Imperial Valley. It also presents the best management practices (BMP's) to achieve the above objective and describes the demonstration project that was conducted at the University of California Desert Research & Extension Center (UCDREC) between 1995 and 1999 to evaluate the effectiveness of this new method.

An alluvial, moderately saline (EC^{-} 6-8 dS/m in the rootzone) clay soil at UCDREC, Holtville, CA, was cultivated and sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Alfalfa was planted in November 1995 (Field No. 2) followed by a corn planting on the same ground in February 1999. A total of 15 acres were used in this project. The area was divided into 2 fields each containing separate plantings of alfalfa (followed by corn) and sudangrass. Each field contained 4 borders; each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to determine soil moisture, water table elevation and quality, and soil salinity at different depths. Moisture contents at all sampling locations were measured using a neutron probe. Soil moisture measurements were made prior to irrigation and 2 or 3 days after irrigation. Alfalfa and sudangrass hay yields were determined for every cutting.

Significant amount of runoff water was saved as a result of the implementation of this method. Overall only 2% of the applied water became runoff resulting in a significant increase in water application efficiency. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield was not affected by the surface runoff reduction treatment and resulted in similar water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average applied water use efficiencies (AWUE's) of 1.77 tons of sudangrass per ac-ft/ac and 1.76 dry tons of alfalfa per ac-ft/ac. The corresponding WUE (includes AW, rain and WT contributions to ET of the crop) figures for sudangrass and alfalfa were 1.75 and 1.54, respectively. This alfalfa AWUE value (i.e. 1.76) compared more favorably with the CA and AZ statewide (1998) average AWUE's of 1.80 and 1.49 dry tons of alfalfa per ac-ft/ac, respectively, as compared to the Imperial Valley (1996-1998) average AWUE of 1.17 tons of alfalfa per ac-ft/ac.

We found that shutting off the applied water at when the surface wetting front reached approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border while reducing runoff to only 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. After three years, the average crop coefficient for sudangrass during the entire growing seasons was approximately 0.81.

An increase in soil salinity of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction method.

Additional work is needed to verify the applicability of this method to commercial fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is common in the Imperial Valley.

1.2 Introduction

Colorado River water is the only source of irrigation and drinking water in the Imperial Valley. Approximately 17% of the irrigation water delivered in the Imperial Valley later re-appears as tailwater. Efficient irrigation practices are needed to minimize surface runoff and to reduce the amount of chemicals translocated downstream in runoff water. The Salton Sea water surface elevation has recently reached the highest level on record since 1920. Surface runoff and subsurface drainage water from agricultural lands in Imperial Valley contribute to this increase in Salton Sea elevation. Currently, the salinity of the Sea is over 47,000 ppm, approximately 30% greater than the salinity of the Pacific Ocean.

Issues related to salinity, irrigation management, and water quality are also addressed in this report. The focus of this report is on field crops, specifically alfalfa and sudangrass. In 1998, field crops accounted for almost 80% of the nearly 500,000 acres of irrigated land in the Imperial Valley while heavy clay soils represents more than 60% of the irrigated land. Alfalfa and sudangrass water use account for more than 50% of the total crop water use in the Valley.

This publication summarizes the results of work conducted by the authors at the University of California Desert Research and Extension Center (UCDREC) to develop and demonstrate a simple field procedure to determine the irrigation cutoff time in cracking clay soil so that runoff losses are minimized. This research and demonstration project was conducted at UCDREC to verify the effectiveness of this method and its possible impact on alfalfa and sudangrass production in the Imperial Valley. The Center clay soils are typical of a major portion of the Imperial Valley.

2. Objectives/additional objectives

The original objectives of the project were to:

2.1 Determine the best management practices (BMPs) for surface runoff reduction in heavy clay soils of the Imperial Valley.
2.2 Determine the effect of water table control on irrigation management and consumptive use of water by alfalfa and sudangrass (including crop coefficients for alfalfa and sudangrass).
2.3 Determine the contribution of shallow saline water tables to crop evapotranspiration in heavy clay soils.
2.4 Develop a relatively simple approach to predict irrigation cutoff time from pre-determined soil moisture measurements.
2.5 Develop a user-friendly computer program and irrigation management spreadsheets for efficient irrigation management practices. These tools include: the use of CIMIS data for irrigation scheduling, prediction of crop water requirements for alfalfa and sudangrass, and prediction of seasonal changes in AE, DU, and surface runoff.
2.6 Conduct field days, demonstrations, seminars, and publish results in both popular and scientific media.

Additional objectives were added during the course of the experiment to address concerns/issues that were raised during the Project Advisory Committee (PAC) meetings. These included addressing the following concerns:

2.7 Assess the impact of runoff reduction on hay quality.
2.8 Assess the impact of runoff reduction on soil salinity.
2.9 Evaluate alfalfa root distribution.
2.10 Assess the impact of the runoff reduction method on subsequent crop production.
2.11 Assess the impact of two irrigation per cutting versus one irrigation per cutting on alfalfa yield in summer 1997.

3. Methodology

Alluvial clay soil of Areas 70 and 80 at the UCDREC, Holtville, CA, was cultivated. The 15-acre project area was divided into 2 fields each containing separate plantings of alfalfa and sudangrass. Alfalfa was planted in November 1995 (Field No. 2). Sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Each field contained 4 borders where each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to evaluate soil moisture distribution and soil salinity at different depths (Figure 14). Moisture contents at all sampling locations were determined using a neutron probe as described by Grismer et al. (1995). Soil moisture measurements were made prior to and 2 or 3 days after irrigations. Colorado River water was applied to all fields. During the first year of the study, most irrigations began between 6-7 am and ended between 5-7 PM. We used a reservoir at UCDREC, that was filled with water from an IID canal the previous day, to start the irrigations for approximately 2-3 hours until IID canal water became available at approximately 9 AM. At the end of each irrigation excess water ordered from the IID was stored in the reservoir to irrigate other crops at the Center (IID water orders were for either 12 or 24-hour runs). During the last year of the project and in response to issues raised by the PAC, we changed the timing of the irrigations such that we started the irrigation in either the afternoon (4-7PM) or at night (11PM-3AM) and irrigated directly from the IID canal. Such irrigation scheduling better represented the irrigation practices of commercial fields in the Valley. Except for a few occasions when the IID canal water ran dry during an irrigation event, we had complete control of when to turn the water on or off to the field.

Thirty-two 9-ft neutron probe access tubes were installed in each field (eight neutron probe access tubes were installed in each border). The probes were used to characterize soil moisture distribution in each field. Moisture measurements were taken at depths of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, and 9.0 ft prior to and 48-72 hours following each irrigation. Gravimetric soil moisture samples were taken in the 0-6" depth range because the neutron scattering technique does not accurately estimate soil moisture content near the surface. Evapotranspiration during and for the two or three days following irrigations were obtained from CIMIS weather station No. 87 and was added to the difference in soil moisture prior to and following each irrigation. Thirty-two 10-ft deep observation wells were installed in each field. The observation wells were used to determine water table elevation and to extract water samples from the shallow groundwater. Water samples from each well were taken for determination of salinity and Cl concentrations. Soil samples from the 32 locations in each field were taken at various depths (0-108") and times to evaluate the temporal and spatial distribution of soil salinity.

Soil preparation, planting rates, varieties, fertilization, and pest control were preformed according to the UCCE guidelines to production and practices for Imperial County-Field Crops (UCCE Circular 104-F) and alfalfa production in the low desert valley areas of California (UC DANR leaflet 21097). Alfalfa was cut at approximately 10% bloom. Hay was baled at moisture contents of approximately 10-15%. Except for irrigation management, alfalfa and sudangrass cultural practices used for this study followed the normal agricultural practices at UCDREC and were presumably typical of that found in the Valley.

Water conservation and management was the focus of this work and the primary changes to water management from that typical in the Valley included the following:

- Control of the duration of irrigation to ensure that the runoff water is minimized or eliminated (alfalfa and sudangrass fields).
- Reduce the frequency of application to utilize the shallow ground water (alfalfa field).

After the termination of the study, corn was planted on the alfalfa field in February 1999 and harvested in June 1999 to address the impact of this method on soil salinity and yield of a subsequent crop.

According to UCCE guidelines to production and practices (Mayberry et al., 1996), approximately 6.5 ac-ft/ac of water are used annually on alfalfa in the Imperial Valley (approximately 16 irrigations per year). The average application per irrigation is approximately 5 inches. Approximately ½ ac-ft/ac of water is used for land preparation and approximately another ½ ac-ft/ac is used for leaching. One to three irrigations per cutting are necessary depending on the soil type and time of the year (Mayberry et al., 1996). On clay soils, it is recommended to cut off the irrigation water when it is about 80% down the length of the field (Mayberry et al., 1996) to avoid crop scalding during late summer periods. Average water use on sudangrass in the Imperial Valley is approximately 4.8 ac-ft/ac (Mayberry et al., 1996). The salinity of Colorado River water is approximately 1.05-1.10 dS/m. Approximately ½ ton of salt per acre is added to the root zone in a typical irrigation. Leaching irrigations after crop termination are common and necessary to maintain a rootzone salt balance in Imperial Valley fields.

In 1998, field crops accounted for almost 80% of the 500,000 acres of irrigated land in the Imperial Valley. Alfalfa and sudangrass water use accounts for more than 50% of the total crop water use in the Imperial Valley (Tables 9 & 10).

Table 9. Alfalfa production in the Imperial valley

Year	Acres	Tons/ac	Value $/ton
1995	182,401	7.88	87.98
1996	161,116	7.56	101.84
1997	165,922	7.56	117.91
1998	178,517	7.65	93.64

Source: 1995-1998 Imperial County Agricultural Crop & Livestock reports

Table 10. Sudangrass production in the Imperial valley

Year	Acres	Tons/ac	Value $/ton
1995	77,365	6.50	85.00
1996	85,896	6.36	86.33
1997	87,562	5.56	98.77
1998	70,068	4.91	99.37

Source: 1995-1998 Imperial County Agricultural Crop & Livestock reports

4. Results and Discussion

4.1 Soil type:

According to Zimmerman (1981), Area 80 (alfalfa field) consists of soil types 106 (Glenbar clay loam), 110 (Holtville silty clay), and 115 (Glenbar silty clay loams) while Area 70 (sudangrass field) consists of soil types 114 (Imperial silty clay) and 115 (Glenbar silty clay loams). The published water-holding characteristics of the above soils are summarized in Table 11.

Table 11. Water holding characteristics of soils in areas 70 and 80 of UCDREC.

Soil type	Maximum depth (in)	Available water (in/in) --- depth (inches) --- 0-24	24-48	48+
Alfalfa field				
Glenbar 106 & 115	60	0.20	0.20	0.20
Holtville 110	60	0.21	0.14	0.09
Sudangrass field				
Imperial 114	60	0.21	0.21	0.21
Glenbar 115	60	0.20	0.20	0.20

Allowable depletion: 50% for most crops,
50-65% for crops that are relatively insensitive to water stress.

*Source: Water-Holding Characteristics of California soils- University of California, DANR Leaflet 21463.

The soils of the field used for the alfalfa trials were classified as Glenbar clay loam (moderately slow permeability and very high water available water capacity); Holtville silty clay loam (slow permeability in the clayey and moderately rapid in the underlying material, high to very high available water capacity) and Glenbar silty clay loams (moderately slow permeability and very high available water capacity). The soils of the fields used for the sudangrass trials were classified as Imperial silty clay (slow permeability and very high available water capacity) and Glenbar silty clay loams (moderately slow permeability and very high available water capacity).

According to Zimmerman (1981), the soils of the fields selected for the trials are representative of those in the Valley as Glenbar silty clay loam is found on 21 % (203,659 acres) of the Valley, while Holtville silty clay is found on 7 % (70,547 acres), Imperial silty clay on 12.5% (123,401 acres), and Glènbar clay loam on 0.4% (4,239 acres). Forty-eight soil samples were collected from 8 locations in the alfalfa field. The average clay content and soil texture classification of these soil samples are summarized in Table 12.

The soil in Area 70 is characterized by approximately 6 ft of relatively uniform silty clay to clay surface soil with montmorrilonic clay contents ranging from 50 to 70% (Grismer and Tod, 1994 and Grismer and Bali, 1997). The average clay content and soil texture of soil samples collected by Dr. Frank Robinson (UCDREC) from Area 70 are presented in Table 13.

Table 12. Soil texture classification and clay content of the alfalfa field.

Depth (in)	Clay content* (%)	Texture*	Clay range (%)	Texture range**
Surface	60	Clay	55-63	6 Clay, 1 SC, 1 SCL
6	59	Clay	55-63	7 Clay, 1 SC
12	58	Clay	47-65	8 Clay
24	59	Clay	55-65	8 Clay
36	48	Clay	19-67	6 Clay, 1 SL, 1 SNC
48	38	Clay loam	27-49	2 Clay, 3 CL, 1 SC, 2 SNCL

*Average of 8 locations (48 samples).
**SC: Silty clay, SCL: Silty clay loam, SL: Silt loam, SNC: Sandy clay, SNCL: Sandy clay loam.

Table 13. Soil texture classification and clay content of the sudangrass field.

Depth (in)	Clay content* (%)	Texture*	Clay range (%)
0-12	52	Clay	40-59
12-24	58	Clay	48-68
24-36	61	Clay	40-72
36-48	67	Clay	62-77
48-60	69	Clay	64-76

*Average of 10 locations (50 samples)
Source: Dr. F. Robinson, UCDREC

4.2 Sudangrass field cultural practices

1996 Season: Sudangrass (cv. 'Piper') was planted on April 15, 1996.
1997 Season: Sudangrass (cv. 'Piper') was planted on April 18, 1997.
1998 Season: Sudangrass (cv. 'Piper') was planted on April 14, 1998.
Seeding rates: following the standard practices for uniform crops at UCDREC.
Fertilizer: following the standard practices for uniform crops at UCDREC.
Pest control and harvesting: following the normal practices for uniform crops at UCDREC.

4.2.1 Irrigation dates and average depth of application

The irrigation turnouts (concrete pipes connecting the irrigation supply canal to field borders) at UCDREC were calibrated to establish a head-discharge relationship (Tod et al., 1991). The amount of water applied to each border was then measured using the method of Tod et al. (1991). Water-pressure head losses across the irrigation turnouts were measured on gages located at the downstream end of the irrigation turnouts. Measurements were taken approximately every 30 minutes during irrigation events. Plate valves that control flow through the turnout pipes were removed completely during irrigations.

Average onflow rate and depth of water application were determined for each irrigation and this data is given in Tables 14-16. Overall irrigation frequency and applied water (AW) depths as well as total number of cuttings for the sudangrass are summarized in Table 17.

Table 14. Irrigation information (sudangrass field) - 1996 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
1-18-96 (pre-irrigation)	3.87	Pre-irrigation	Pre-irrigation	Pre-irrigation	-	*	-
4-16-96	3.95	First irrigation	First irrigation	First irrigation	1	1132	99
5-3-96	2.84	5.04	0.00	0.56	1	959	98
5-24-96	5.08	7.57	0.00	0.67	0	874	95
6-28-96	6.92	11.51	0.00	0.60	0	908	89
7-23-96	5.72	7.87	0.00	0.73	0	862	93
8-20-96	6.94	8.43	0.00	0.82	0	868	97
9-17-96	6.05	7.40	0.00	0.82	0	860	100
Totals or Averages (4/16 to 10/10/96)	**37.50** (3.13 ac-ft/ac)	**53.40**	**0.00**	**0.70**	**0**	**923** (889 w/o 1st irrg.)	**96**

* Avg. cutoff distance 1150 ft (Runoff reduction method was not used for the pre-irrigation)

Table 15. Irrigation information (sudangrass field) - 1997 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
4-21-97	5.69	First irrigation	First irrigation	First irrigation	0	992	95
5-5-97	1.73	4.12	0.00	0.42	2	797	99
6-2-97	7.42	8.48	0.00	0.88	0	881	87
6-20-97	5.35	5.63	0.00	0.95	3	921	100
7-9-97	5.70	6.50	0.00	0.88	3	888	100
7-29-97	5.18	5.64	0.00	0.92	4	874	100
8-20-97	6.04	6.40	0.00	0.94	3	856	100

9-10-97	5.47	4.98	0.16	1.13	4	873	100
10-10-97	3.63	5.82	1.02	0.80	4	853	100
Totals or Averages (4/21 to 11/25/97)	**46.21** **(3.85 ac-ft/ac)**	**53.83**	**1.18**	**0.88**	**3**	**882** (868 w/o 1st irrg.)	**98**

Table 16. Irrigation information (sudangrass field) - 1998 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
4-15-98	5.49	First irrigation	First irrigation	First irrigation	1	1062	99
4-22-98	2.28	1.74	0.00	1.30	0	836	98
5-20-98	5.53	7.59	0.00	0.72	4	918	100
6-17-98	6.04	8.31	0.00	0.73	2	957	100
7-8-98	5.77	6.77	0.00	0.85	2	850	100
7-29-98	5.54	6.03	0.04	0.92	4	843	100
8-20-98	4.59	5.88	0.12	0.78	0	700	91
Totals or Averages (4/15 to 9/8/98)	**35.24** (2.94 ac-ft/ac)	**41.20**	**0.16**	**0.86**	**2**	**881** (851 w/o 1st irrg.)	**98**

Table 17. Depths of water applied and number of cuttings for the sudangrass field.

Year	No. of irrigations	Total AW (in)	AW depth (in)	No. of cuttings
1996	7	41.37*	5.17	3
1997	9	46.21	5.13	3
1998	7	35.24	5.03	2

* includes pre-irrigation
Leaching irrigation: 6.20 inches

After the termination of crop production, the sudangrass field was disked and subsoiled according to the standard practices at UCDREC. A leaching irrigation was conducted in December 1998 where an average depth of 6.2 in. of water was applied.

Implementation of the runoff reduction method requires that the user either determine the cutoff time or cutoff distance necessary to minimize runoff. Since it is easier for irrigators to use the cutoff distance rather time, the focus of our discussion here will be on the cutoff distance. With the exception of the first irrigation, the average cutoff distance in 1996 was 889 ft from the border's inlet or approximately 71% of the field's length (as compared to the maximum distance of 80% recommended by Mayberry et al,. 1996). We obtained no runoff at this cutoff distance and surface wetting reached 96% of the field length. In 1997 and 1998, the average cutoff distances for all irrigations except the first irrigation were 868 and 851 ft, respectively, resulting in surface wetting of 98% of the field. We found that the optimum cutoff distance to minimize or eliminate runoff varies from 850 to 950 ft or approximately 70 to 75% of the field's length. Our overall average cutoff distance was 870 ft or approximately 70% of the field's length (for all irrigations except first irrigations). The average cutoff distance for the first irrigations was larger (1062 ft or 85% of the field length) due to the newly-disked surface preparation of the field.

Except for the first irrigation, we found that cutting the applied water at approximately 75% of the field length resulted in sufficient water coverage to irrigate the entire border and have some runoff ranging from 1-4% of applied water. A cutoff distance of approximately 80-85% of the field's length is needed for the first irrigation to insure that enough water reaches the lower end of the field for seed germination. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season. Since cracks are not present prior to the first irrigation, the cutoff method should not be used on the first irrigation. Instead, we found the traditional two-point method (Elliott and Walker, 1982) could be used to estimate the cutoff distance for the first irrigation of the season. However, for simplicity, a cutoff distance of approximately 80-85% of the field length is recommended to ensure that enough water reaches the lower end of the field.

4.2.2 Average yields

Sudangrass was grown for three consecutive -growing seasons. After the first season, an oat crop was grown in Area 70 between December 1996 and February 1997 (a uniform cropping practice for UCDREC hay production). Sudangrass was harvested according to the normal practices of harvesting a uniform crop at UCDREC. Yields were measured by cutting and weighing the crop from representative samples areas along each border as well as by commercial harvesting methods. Average sudangrass yields reported in Tables 18-20 are based on weighing 10-15 sudangrass bales in the field after each cutting.

Table 18. Average sudangrass yield - 1996 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
6-17—96	2.38	2.37
8-7-96	2.25	2.24
10-10-96	2.13	2.23
Total 1996	**6.76**	**6.84**

Table 19. Average sudangrass yield - 1997 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
7-1-97	3.07	2.99
10-3-97	2.36	2.32
11-25-97	0.62	0.59
Total 1997	**6.05**	**5.90**

Table 20. Average sudangrass yield - 1998 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
6-29-98	2.90	2.66
9-8-98	2.42	2.18
Total 1998	**5.32**	**4.84**

The annual water use by the sudangrass between 1996 and 1998 ranged from 35 inches to 46 inches. The average crop coefficients were 0.70, 0.88, and 0.86 in 1996, 1997, and 1998, respectively. We varied the irrigation frequency from seven irrigations per growing season in 1996 to nine irrigations per season in 1997 to evaluate the impact of varying irrigation frequency on applied water use efficiency (AWUE)of sudangrass (average yield per unit water applied). These results for sudangrass AWUE are presented in Table 21.

Table 21. Sudangrass applied water use efficiency (tons per ac-ft/ac)

Cut number	Avg. depth of AW (inches)	Average yield (tons/acre) adjusted to 10% moisture	AWUE (tons per ac-ft/ac)	No. of irrigations/cut
1st cut 1996	11.87	2.37	2.40	3
2nd cut 1996	12.64	2.24	2.13	2
3rd cut 1996	12.99	2.23	2.06	2
1st cut 1997	20.19	2.99	1.78	4
2nd cut 1997	22.39	2.32	1.24	4
3rd cut 1997	3.63	0.59	1.95	1
1st cut 1998	19.34	2.66	1.65	4
2nd cut 1998	15.90	2.18	1.65	3
Total/*Avg.*	118.95	17.58	***1.77***	***3***

We obtained an overall average AWUE of 1.77 tons of sudangrass per ac-ft/ac of water applied. AWUE was greatest in 1996 and increased as the number of irrigations per cutting decreased. The average crop coefficient was greater in 1997 and 1998 than 1996, due to the greater evaporation rates from the wetter soils. The soil surface remains wet for several days while evaporation continues at the full rate due to the ability of the clay soil to retain moisture and remain saturated as its bulk density increases. Clay soils have the ability to remain fully saturated for 3-4 days following an irrigation event as soil bulk density increases to compensate for the lost water (evaporation). Therefore, AWUE is improved by reducing the irrigation frequency from four to three irrigations per first cutting and from three to two irrigations for the second and third cuttings. Moreover, the relatively high AWUE we obtained is also due to the fact that surface runoff was minimized (overall average runoff was approximately 2%).

4.2.3 Sudangrass hay quality

Sixteen hay samples from bales harvested along the four borders were collected for hay quality determinations. Crude protein (CP) acid detergent fiber (ADF) and other hay quality parameters such as IVDMD and TDN ((AOAC, 1960, Goering and Van Soest, 1970 and Goering et al., 1973) were determined. The sudangrass hay quality parameters are presented in Figure 15. Crude protein and ADF are the most commonly used parameters to evaluate alfalfa and sudangrass hay quality. Both CP and ADF of the sudangrass hay samples at the lower end of the field were of similar quality to the samples collected from the upper end of the field suggesting that the hay quality across the field was not affected by the reduced runoff treatment. The overall quality of the sudangrass hay is typical of that grown at UCDREC.

4.2.4 Soil salinity

Soil samples were collected from 32 measurement locations at depths to 108"prior to, during, and after the termination of the study (Figure 14). Soil samples were analyzed for salinity and Cl concentrations. Selected samples were also analyzed for other major ions (e.g. Na, Ca, Mg & Na). The average soil salinity distributions for the rootzone (upper 48") are shown in figures 16-21. These figures also show the average salinity distribution along the four sudangrass borders. In general, the salinity levels at 6 and 12-ich depth increments tend to increase from the head to the tail-end of the field. The increase in salinity at the lower end of the field is due to the surface leaching or lateral transport of salts from the soil surface and shallow soil depths (0-12") at the upper end of the field. Rhoades et al. (1997) found the same trend of relatively higher salinity at the tail end of heavy-textured fields in the Imperial Valley. Figure 22 summarizes changes in average soil salinity of the root zone profile at various times during and after the study. Average soil salinity levels ranged from 7.38 dS/m to 8.58 dS/m. The average salinity in the top 48" of the soil profile was the greatest (8.58 dS/m) at the beginning of the study in spring 1996. The average salinity at the end of the study and before the leaching irrigation was 7.90 dS/m which represents an 8% decline in salinity since the beginning of the study. The average salinity level declined further to 7.47 dS/m after leaching. This indicates that sufficient leaching occurred during the study and that the reduced runoff irrigation method did not have an adverse impact on soil salinity. Moreover, the leaching irrigation was not necessary at the end of the sudangrass season. Figure 23 illustrates the changes in soil salinity within the soil profile at various times during the study. Most of the leaching occurred in the top 24-36 inches of the soil profile. Figure 24 illustrates the changes in soil Cl concentration within the soil profile at various times and also clearly indicates that most of the leaching occurred in the top 24-36" of the soil profile.

4.2.5 Water table

Thirty-two 1-inch-diameter observation wells were installed in the field (Figure 14). Water table depth was monitored prior to and following irrigations. Water samples from the observation wells were analyzed for salinity and Cl concentrations. Average water table depth, salinity and Cl concentrations are presented in Figures 25-27. Water table elevation remained nearly constant in 1996. Water table elevation increased by 2-4" immediately following irrigations and both salinity and Cl concentration of the water table decreased as a result of irrigation. In 1997 and 1998, water table elevation increased from about 80" below ground level to about 60-65" below ground level during the cropping season. This indicates that sufficient water was available for adequate leaching. Except for short-term declines after irrigation events, both salinity and Cl concentration of the water table remained nearly constant during each growing season.

4.2.6 Impact of water table control on soil salinity and leaching

An independent experiment was conducted on three borders east of the sudangrass field to determine if water table control (lowering the water table from approximately 5-6 ft to a depth of 12–20 ft below the soil surface) is effective in reducing soil salinity and improving leaching in the rootzone. We utilized part of a skimming drainage well system that was installed in 1992 (Grismer and Bali 1997). The system consists of 26 2-inch diameter wells spaced 20 ft a part in a line along the middle of two borders (borders 1 and 2). Each well draws water from the water table from a depth of 12-20 ft and discharges it via a mainfold connected to a diaphragm pump to a surface drainage canal at the end of the field. The experiment was initiated in August 1996. The three borders were disked and border checks were placed around an area 62 ft wide by 128 ft long to hold water in border 2 during continuous ponding. Groundwater level, water content, and soil salinity were monitored regularly before, during and after the ponding experiment, both inside and outside the flooded area. Five monitoring sites were established, each site had an observation well, NP access tube, and soil sampling location. The pump was turned on in July 96 to lower the water table in and around the study area. In addition, the 62' by 128' area was flooded on Aug. 14 and the ponded water level maintained until Sep. 19 to evaluate continuous flooding leaching potential. Results from this work suggested that lowering the water table was effective in reducing soil water content and was useful in leaching reclamation of clay soils only after continuous surface ponding and groundwater pumping. The shallow drainage-well system alone was effective in controlling water table depth but had little effect on reducing rootzone soil salinity without surface ponding.

4.3 Alfalfa field

Alfalfa was planted on November 7, 1995 and the field was renovated and reseeded in October 1997. Seeding rates, fertilizer use, pest control and harvesting practices followed the standard procedures for uniform crops at UCDREC. Renovation and reseeding of alfalfa fields in heavy soils is a common practice in the Imperial Valley. Alfalfa stand loss in the Valley is common due to variety of causes such as high summer temperatures, high humidity, poor soils, plant damage, wheel tracks of farm equipment, and the ever-present plant diseases (Lehman, 1979). Weak stands of alfalfa on heavy soils may require annual reseeding (Zimmerman, 1981) as thick, uniform stands compete well with weeds and tend to result in higher yields during the first few cuttings (Lehman, 1979).

4.3.1 Irrigation dates and average depth of water application

The irrigation turnouts at UCDREC were calibrated as for the sudangrass field and the amount of water applied to each border was measured using the method of Tod et al. (1991) (see section 4.2.1). We followed the recommendations of Lehman (1979) regarding proper irrigation timing and application of water to minimize summer stand loss. Lehman's recommendation is to irrigate and manage alfalfa fields during August and September with stand survival as the primary concern. However, in this study our primary objective was to improve water use efficiency, or optimizing rather than maximizing yield. Average flow rate and average depth of application were determined for all irrigations (Table 22). Alfalfa irrigation practices and total number of cuttings are summarized in Table 23 for the entire duration of the project.

The average cutoff distance for the entire alfalfa growing period was 887 ft from the border's inlet or approximately 71% of the field's length. This is almost identical to the average cutoff distance of the sudangrass field. We obtained an average runoff of approximately 2% at this cutoff distance and managed to irrigate 99% of the field. Except for the two germination and stand establishment irrigations, the average cutoff distance varied from 797 to 940 ft or from 64 to 75% of the field's length. Flowrate and soil crack size were the main factors affecting the average cutoff distance. We found that the optimum cutoff distance to minimize or eliminate runoff varied from 800 to 950 ft or approximately 65 to 75% of the field's length.

Except for the first two germination and stand establishment irrigations, we found that cutting the water at approximately 75% of the field's length resulted in sufficient water coverage to irrigate the entire border and have some runoff ranging from 1-6% of applied water. A cutoff distance of approximately 85% of the field's length is needed for the first two irrigations to insure that enough water reaches the lower end of the field to germinate alfalfa. As noted for the sudangrass field, the method of Grismer and Tod (1994) may be used to estimate the volume of cracks in heavy soils for all irrigations except the first two irrigations. Since cracks are not present prior to the first two irrigations, the cutoff method should not be used. Instead, we found the traditional two-point method (Elliott and Walker, 1982) could be used to estimate the cutoff distance for the first two irrigations. However, for simplicity, a cutoff distance of approximately 85% of the field's length is recommended and is adequate to ensure that enough water reaches the lower end of the field.

Table 22. Irrigation information - Alfalfa field

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
11-8-95	3.91	First irrigation	First irrigation	First irrigation	2	1115	99
12-4 & 12-5-95	3.53	2.50	0.00	1.41	7	1020	99
1-22 & 1-23-96	5.01	3.64	0.04	1.39	6	868	100
3-19-96	5.52	7.65	0.12	0.74	4	896	100
4-24-96	6.13	9.46	0.00	0.65	1	885	100
5-17-96	5.62	7.59	0.00	0.74	2	894	99
6-7-96	4.99	7.16	0.00	0.70	0	832	93
7-3-96	5.57	8.61	0.00	0.65	2	878	100
8-2-96	5.49	9.23	0.00	0.59	0	853	97
9-10-96	5.28	11.11	0.00	0.48	0	875	94
11-1-96	5.30	10.75	0.00	0.49	1	876	97
12-20-96	4.19	4.38	0.00	0.96	2	897	100
2-19-97	4.37	5.90	0.32	0.79	2	852	100
4-7-97	4.65	9.29	0.12	0.51	0	797	95
4-28-97	4.66	5.91	0.00	0.79	2	834	100
5-19-97	4.57	5.88	0.00	0.78	1	855	100
6-16-97	4.47	8.75	0.00	0.51	0	917	97
7-11-97	5.27	8.46	0.00	0.62	1	932	98
7-23-97*	1.42 (only two borders irrigated, 2.84")	3.20	0.00		1	798	100
8-8-97	4.80	4.85	0.00	0.99	3	940	100
8-19-97*	1.79 (only two borders irrigated, 3.58")	3.08	0.00		2	856	100
9-5-97	4.59	4.13	0.00	1.11	1	922	100

					2	918	100
10-18-97	4.60	8.45	1.18	0.68	1	880	99
11-14-97	3.40	3.68	0.00	0.92	1	900	99
2-13-98	4.58	6.89	1.19	0.84	3	942	100
3-20-98	4.60	4.77	0.59	1.09	2	911	99
4-17-98	5.15	5.77	0.16	0.92	1	779	100
4-29-98	3.24	3.20	0.00	1.01	0	870	98
5-15-98	4.39	4.42	0.00	0.99	2	861	99
5-27-98	3.87	3.24	0.00	1.19	2	902	98
6-12-98	4.70	3.63	0.00	1.29	2	911	100
6-26-98	4.55	5.76	0.00	0.79	0	817	97
7-14-98	5.07	5.57	0.00	0.91			
Totals or Averages (11/8/95 to 8/4/98)	**149.28** (12.44 ac-ft AW/ac)	**202.94**	**3.72**	**0.75** (w/o WTC) 0.84 (including WTC)	**2**	**887** (880 w/o 1st irrig.)	**99**

*Two out of four borders received extra irrigation on these dates at the request of the project advisory committee. The objective here was to evaluate the impact of two irrigation versus one irrigation per cutting on alfalfa yield. The average alfalfa yield on these two borders was 27 and 31% higher as compared to the other two borders that received one irrigation per cutting.

Table 23. Summary of the amount of water applied and number of cuttings for the alfalfa field.

Year	No. of irrigations	Total AW (in)	Avg. AW depth (in)	No. of cuttings
1995	2	7.44	3.72	Stand establishment
1996	10	53.10	5.31	8
1997	12[1]	48.59	4.42	8[2]
1998	9	40.15	4.46	7

[1] Includes two irrigations where only 2 borders (out of 4) were irrigated (see previous table).
[2] One cutting lost due to insect damage.
Leaching irrigation: 6.06 inches.

4.3.2 Average yields

Alfalfa yields were measured by cutting and weighing the crop from representative samples areas along each border as well as by commercial harvesting methods. Average alfalfa yields reported in Table 24 are based on weighing alfalfa samples collected from 20' by 3' sections adjacent to NP locations.

Table 24. Average alfalfa yields.

Cut date	Average yield (tons/acre) dry matter	Average yield (tons/acre)adjusted to 10% moisture
3-4-96	1.23	1.35
4-17-96	1.25	1.38
5-28-96	1.70	1.87
6-24-96	1.77	1.95
7-24-96	1.29	1.42
8-27-96	0.87	0.96
10-15-96	0.82	0.90
12-9-96	0.62	0.68
2-4-97	0.59	0.65
3-27-97	Insect damage	Insect damage
5-7-97	1.20	1.32
6-5-97	1.19	1.31
7-7-97	0.92	1.01
8-1-97	0.95	1.05
8-29-97	0.86	0.95
10-7-97	0.60	0.66
1-21-98	0.56	0.62
3-10-98	0.70	0.77
4-10-98	0.83	0.91
5-8-98	1.10	1.21
6-8-98	1.18	1.30
7-6-98	1.19	1.31
8-4-98	0.45	0.50
Totals	**21.87**	**24.06**

The average alfalfa yield distributions along the border for each cutting are shown in Figures 28-32 based on yield measurements obtained at each of the 32 measurement locations. For selected cuttings, we obtained continuous yield measurements at 20 ft intervals along each border (approximately 230 yield measurements per cutting). The yield distributions along the field for one of these cuttings are shown in Figure 33. For most summer cuttings (June-September), alfalfa yield declines at the lower end of the field. The decline in alfalfa yield is due to a combination of reduced water application and high salinity (greater water table contributions) at the lower end of the field. The decline at the lower end of the field is less visible between October and May cuttings (Figure 34). The overall average yield loss due to yield reduction at the lower end of the field is approximately 1.5% of the expected yield of the entire field. However, under normal irrigation practices on heavy clay soils in the Imperial Valley, almost the entire alfalfa yield at the lower end of the field is commonly lost to scalding. One of the advantages of the runoff reduction method is our ability to maintain a good stand of alfalfa at the lower end of the field and prevent or minimize scalding.

Following alfalfa production, the field was disked and sweet corn was planted to assess the possible salinity impacts of the surface runoff reduction method on subsequent crops. Two sets of 32 samples of corn were taken in April and May 1999 from 3.3-ft furrow sections next to the 32 measurement locations. Corn dry matter distributions along the field are shown in Figure 35. Corn yield measurements were also obtained at each of the 32 measurement locations in June 1999. Corn dry matter and yield measurements at the lower end of the field were not significantly different from those obtained at the upper half of the field. As in the sudangrass field this result suggests that there was no adverse salinity accumulation in the field from the three years of the surface runoff reduction method of irrigation.

The average crop coefficient ((AW+rain+water table contribution, WTC)/ET_o)) for the entire alfalfa growing season was 0.84. The WTC component is discussed in detail below (Section 4.3.7). We varied the irrigation frequency from one to two irrigations/per cutting to maximize the upward movement of water from the water table to the root zone. Utilizing the water table, reducing irrigation frequency, and minimizing surface runoff maximized our alfalfa water use (WUE) efficiency figures where WUE is defined as the dry tons of alfalfa yield obtained per unit water use (including AW, WTC, and rain). Our overall average WUE was 1.54 dry tons of alfalfa per ac-ft/ac of water used and the AWUE (i.e. Yield/AW) was 1.76 dry tons of alfalfa per ac-ft/ac. WUE's for each cutting can be calculated from the water use and yield values presented in the previous tables. As noted by Lehman (1979), we generally obtained the maximum WUE in late winter and early spring cuttings.

4.3.3 Alfalfa hay quality

Sixteen hay samples from bales harvested along the four borders were collected for determination of hay quality parameters. Crude protein (CP) acid detergent fiber (ADF) were measured. The results of the alfalfa hay quality analyses are shown in Figure 36. Both CP and ADF of the alfalfa hay samples at the lower end of the field were of similar quality to the samples collected from the upper end of the field. This indicates that the hay quality at the lower end of the field was not affected by the reduced runoff treatment. The overall quality of the alfalfa hay is typical of uniform alfalfa hay quality grown at UCDREC.

4.3.4 Soil salinity

Soil samples were collected from 32 measurement locations at depths to 108"prior to, during, and after the termination of the study (Figure 14). Soil samples were analyzed for salinity and Cl concentrations. Selected samples were also analyzed for other major ions (e.g. Na, Ca, Mg & Na). The average soil salinity distributions for the rootzone (upper 48") between November 1995 and May 1999 are shown in Figures 37-44. The figures also show the average salinity distribution along the four alfalfa borders. In general, the salinity levels at 36" and 48" depth increments tended to increase from the head to the tail-end of the field. The increase in salinity at the lower end of the field is most likely due to the upward movement of water from the water table. Soil of the lower half of the profile has relatively lower clay contents than the upper half (see Table 12) and therefore has a higher hydraulic conductivity which enables greater rates of upward movement of water within the lower half of the soil profile. Unlike the Sudangrass field, surface leaching or lateral transport of salts from the soil surface and shallow soil depths (0-12") at the upper end of the field was not observed until August 1998. Lateral transport of salts was evident after the leaching irrigation (Figure 43).

Figure 45 summarizes changes in average soil salinity of the root zone profile between November 1995 and May 1999. Despite the increase in average soil salinity during the alfalfa growing period, soil salinity levels after one leaching irrigation and planting and irrigating sweet corn returned to salinity levels at or below pre-study levels (Figs. 45 and 46). The average salinity of the soil profile (0-108") for various dates is shown in Fig. 47. Little change in soil salinity occurred at the upper half of the soil profile (0-24") during or after the study. Most of the changes occurred at depths below 24 inches due to the upward movement of water from the water table. It is clear that most of the soil salinity changes occurred between January 1996 and March 1997. We found this to be strongly correlated to water table contribution figures where most of the water table contribution occurred during the first year of the study. Average chloride concentrations within the soil profile also indicated that most of the water table contribution occurred during the first year of the study (Fig. 48).

4.3.5 Water table

Thirty-two 1-inch-diameter observation wells were installed in the field (Figure 14). Water table depth was monitored prior to and following irrigations. Water samples from the observation wells were analyzed for salinity and Cl concentrations. Average water table depth, salinity and Cl concentrations are shown in Figure 49. Water table elevation was relatively high at the beginning of the study (55-65" below ground level) then declined to about 75-80' during the first summer. Water table decline in the first summer and an accompanied increase in soil salinity at levels at below 36" clearly indicates that water table contribution to crop water use was significant during the first year of the study. In general water table elevation declined in summer months of 1997 and 1998 but didn't reach the depths occurring the previous summer (1996). In general, water table elevation increased by 2-4" immediately following irrigations and both salinity and Cl concentration of the water table decreased as a result of irrigations. Except for short term declines after irrigation events, both salinity and Cl concentration of the water table remained nearly constant during the study (Fig. 49).

4.3.6 Impact of water table control on salinity and water table level

The drainage system of Area 80 (approximately 36 acres) is composed of nine diagonally-oriented 4"-diameter tile drains on a 150-ft spacing. The laterals drain to an 8"-diameter collector line in the northeast section of Area 80. The subsurface drainage system was blocked at an access manhole to the eastern-most lateral drain and the drainage collector junction in August 1994 and remained blocked for the duration of the alfalfa growing season. In addition to the 32 observation wells that were installed in the alfalfa field, an additional south-north transect of observation wells were installed along the east side of Area 80. Water table levels in this transect were measured on the day the drain was plugged and at intervals of 4 to 21 days after plugging the system. Water table levels in the main alfalfa field were measured prior to and after each irrigation. Water samples from all observation wells were collected at the time of water table measurements. The samples were analyzed for salinity and chloride.

This particular aspect of the study was conducted in conjunction with a larger study to evaluate the effectiveness of subsurface drainage systems at UCDREC (Grismer and Bali, 1998). We had expected to see a gradual rise in water table levels, groundwater salinity Cl concentration due to the addition of irrigation water to the system. After three years of monitoring, we found that average water table levels followed a seasonal variation that reflected the frequency of irrigation. Salinity and chloride concentrations in the south-north transect remained nearly constant. It appears that the presence of deep drainage ditches combined with the shallow fine-sand aquifer below UCDREC controlled groundwater levels below Area 80 and the Meloland area as a whole. We found that plugging the drains to raise water levels to increase the utilization of groundwater contribution for crop evapotranspiration (ET) was of limited effectiveness as a result. Water table contributions to crop ET was also limited due to the high salinity of drainage water and the water retention properties of the clay soils in Area 80. The soil hydraulic properties limited the upward movement of water from the water table to the active rootzone. Details of our efforts to evaluate the effectiveness of drainage systems in clay soils are presented in *California Agriculture* (Grismer and Bali, 1998).

4.3.7 Water table contribution

Water table contributions (WTC) to crop ET depend on the soil hydraulic properties, ET demand, distribution of the crop root system, water table depth, and the salinity of groundwater. We used the mass flow method (Wallender et al. 1979) to estimate the contribution of water table to the evapotranspiration of alfalfa using chloride present in the water table as a tracer to quantify the upward movement of water from the water table to the root zone. We determined the Cl concentration for each 12-inch depth increment of the soil profile in the rootzone (48 inches) at the soil measurement locations in the alfalfa field. Chloride levels in soil, water table, and irrigation water were determined prior to alfalfa planting, five times during the alfalfa growing period, and after leaching. We estimated a maximum water contribution of 12.27 inches between the period of November 1995 and November 1996. During this same period, we applied 56.35 inches of irrigation water (ET_o=79.89 inches). We estimated a maximum water table contribution of 5.3 inches between the period of March 97 and October 1997. During this period we applied 36.22 inches of irrigation water (ET_o=53.55 inches). Water table contributions between November 1996 and March 1997 were negative (i.e. leaching). Water table contributions after October 1997 were also negative. Most of the water table contribution to alfalfa water use occurred during the first year of the study. Maximum water table contributions for various soil depth increments are presented in Table 25.

Table 25. Maximum water table contributions in the alfalfa field.

Depth interval (in)	11/95 - 11/96	11/96 - 3/97	3/97 - 10/97	10/97 – 8/98	Total
0-24	<leaching>		<leaching>		<leaching>
24-36	5.47		2.24		7.71
36-48	6.80		3.06		9.86
Total (0-48)	**12.27**	<leaching>	**5.30**	<leaching>	**17.57**

Total WTC for the entire alfalfa cropping period was less than 18" as compared to the 149" of AW. Approximately 70% of this WTC occurred during the first year of the study. As a result, the salinity of the lower soil profile (36-48) increased to the maximum salinity levels that could be tolerated by alfalfa. Most of the upward water movement was limited to the lower 25% of the root zone profile (36-48"). Most of the alfalfa roots were in the upper 36 inches of the root zone profile (Figure 50). Very little roots were found at depths below 36". However, roots below 36"were found at the lower end of the field suggesting that greater upward water movement occurred at the lower end of the field as compared to the upper end of the field. This observation of root distribution in the soil corresponded well to the observed chloride concentrations at the lower end of the field as noted earlier.

5. Educational Activities

PAC Meetings:

Nov. 1994 DWR/IID tour & presentation
Jan.- Aug. 1995 Draft proposals UCCE/IID

Sep. 1995. First PAC meeting (UC/IID/DWR/USBR)
Nov. 1995 Alfalfa planting
Nov. 1995 UCCE/IID (commercial fields meetings)
Nov. 1995- Nov. 1997 UCCE/IID (commercial fields)
Jan. 1997 second PAC meeting (UC/IID/DWR/USBR)
Jan. 1997 IID-Water Conservation Advisory Board (WCAB) presentation
May 1997 third PAC meeting (UC/IID/DWR/USBR)
Nov. 1997 (10 commercial fields selected)
Dec. 1997 fourth PAC meeting & Comm. field tour (UC/IID/DWR/USBR)
May 1998 fifth PAC meeting (UC/IID/DWR/USBR)
June 1998 WCAB presentation
May 1999 Conf. & sixth PAC meeting

Educational activities:

1997 Two Presentations- Water Conservation Advisory Board (January and April, 97)
1998 UCDREC Alfalfa Field Day
1998 Presentation- Water Conservation Advisory Board (June 98)
1998 Irrigation Workshop (June 98)
1998 CIMIS Workshop-Blythe
1998 CIMIS Workshop-Holtville (June 98)
1998 Salinity Workshop (Nov. 98)
1999 Internet Workshop -CIMIS (March 99)
1999 Irrigation Management & Surface Runoff Reduction Conference (May 19-20, 99)
1995-1998 Eleven field visits (local farmers, IV press, IID, students, consultants)
1996-1999 Three UCDREC Alfalfa Field Days

Computer program and spreadsheet files (please see section I)
Best Management Practices for Runoff Reduction in Clay Soils (Please see section I)

Objectives accomplished were presented to the Project advisory Committee on May, 21, 1998 and May 19, 1999.

Acknowledgements:

- This project was supported by the California Department of Water Resources (45% of the funding) with contributions from USBR (45%) & IID (10%).
- Matching funds from the University of California (UCD & UCCE).
- Land & Labor provided by UCDREC.
- We greatly appreciate the diligent field and laboratory work performed by UCDREC field workers and our research assistants and graduate students.

- We greatly appreciate the contributions made by the project advisory committee (UC, IID, DWR, USBR, NRCS, growers).

6. Conclusions

A significant amount of runoff water was saved as a result of the implementation of the surface runoff reduction irrigation method. Only 2% of applied water was lost to runoff. Water application efficiency was greatly improved by reducing the volume of surface runoff water. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield was not affected by the surface runoff reduction treatment which resulted in significant water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average water use efficiencies of 1.77 tons of sudangrass per ac-ft/ac and 1.54 dry tons of alfalfa per ac-ft/ac.

We found that cutting the water at approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border and reduce runoff to from 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. The average crop coefficient for the sudangrass field for all three-growing seasons was approximately 0.81.

An increase in soil salinity at the lower end of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction irrigation method.

Additional work is needed to verify the applicability of this method to commercial-size fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is the case in the Imperial Valley.

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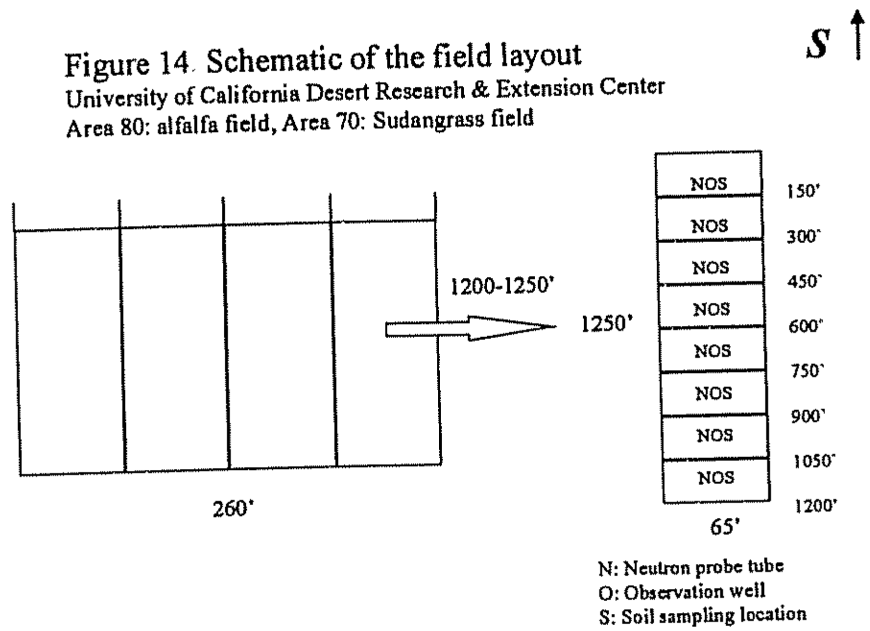
Figures 14-50

Figure 14. Schematic of the field layout
University of California Desert Research & Extension Center
Area 80: alfalfa field, Area 70: Sudangrass field



Map not to scale

Figure 15. Sudangrass hay quality parameters (July 1997)

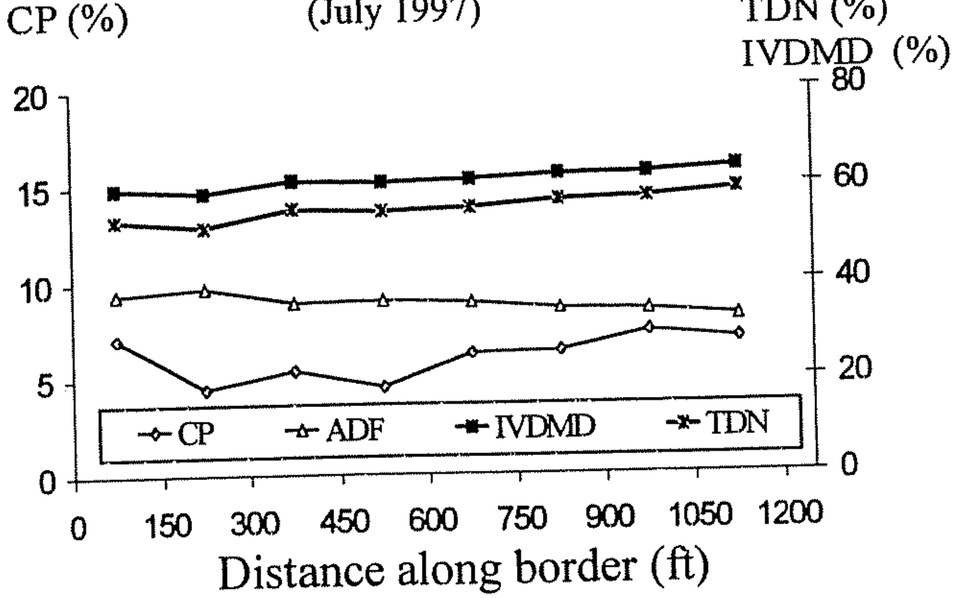


Figure 16. Average Soil Salinity Profiles Along Sudangrass Field, March 1996

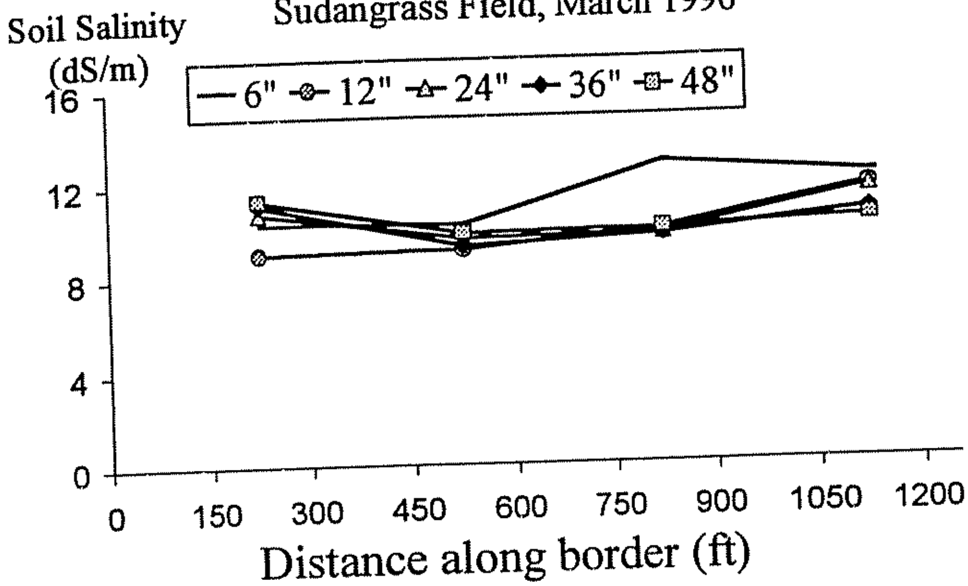


Figure 17. Average Soil Salinity Profiles Along Sudangrass Field, May 1996

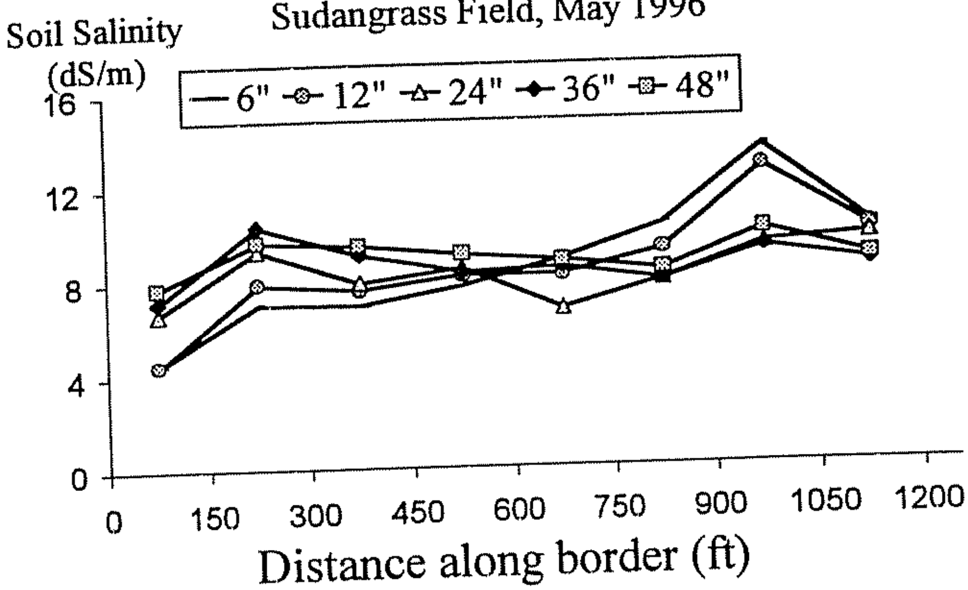


Figure 18. Average Soil Salinity Profiles Along Sudangrass Field, November 1996

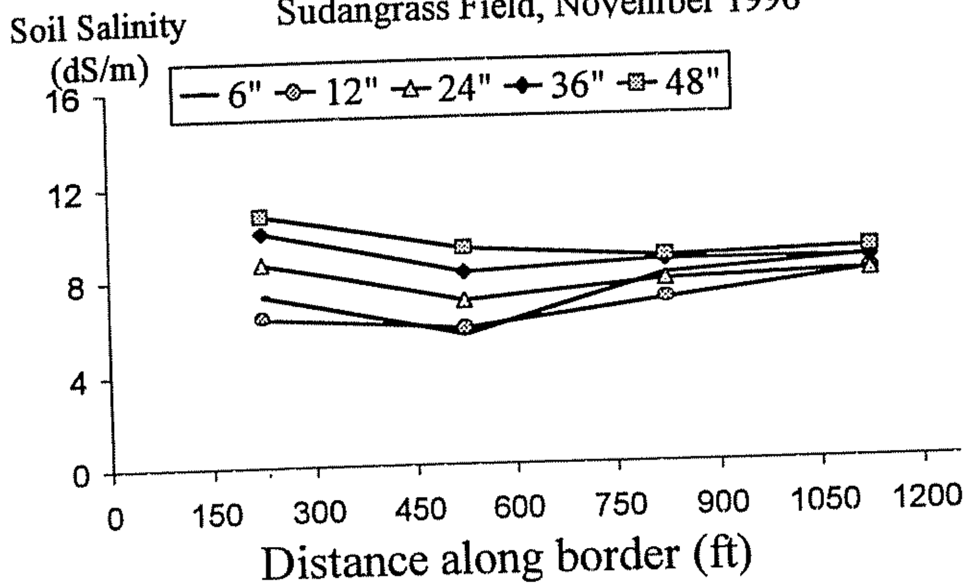
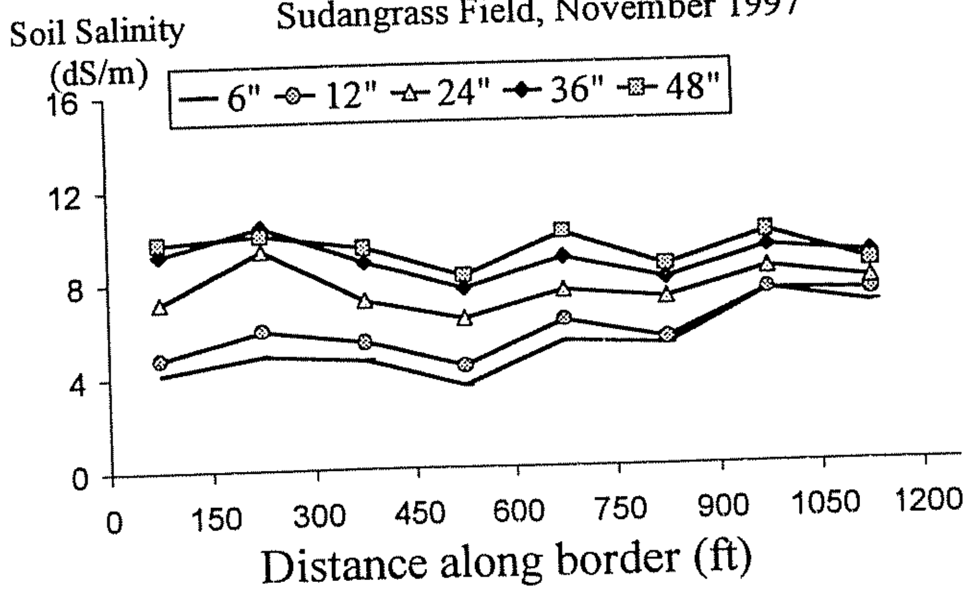


Figure 19. Average Soil Salinity Profiles Along Sudangrass Field, November 1997



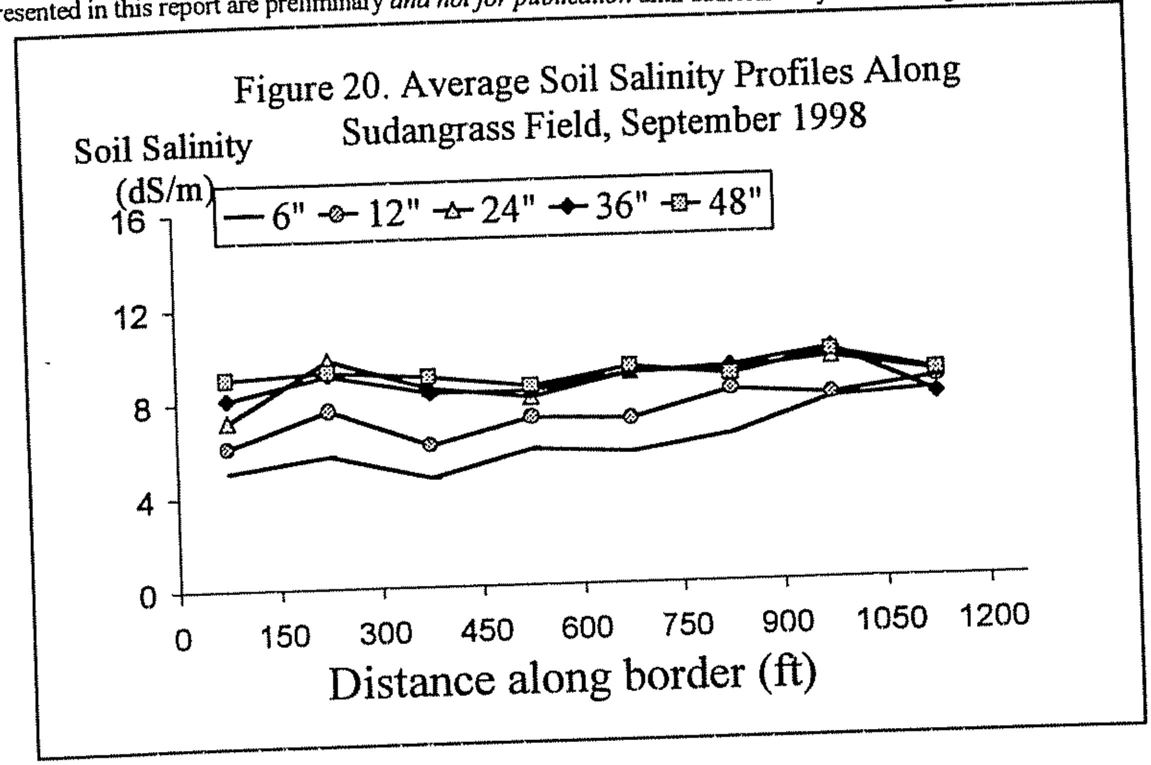


Figure 20. Average Soil Salinity Profiles Along
Sudangrass Field, September 1998
Soil Salinity
(dS/m)
6"
12"
24"
36"
48"
0
4
8
12
16
0
150
300
450
600
750
900
1050
1200
Distance along border (ft)

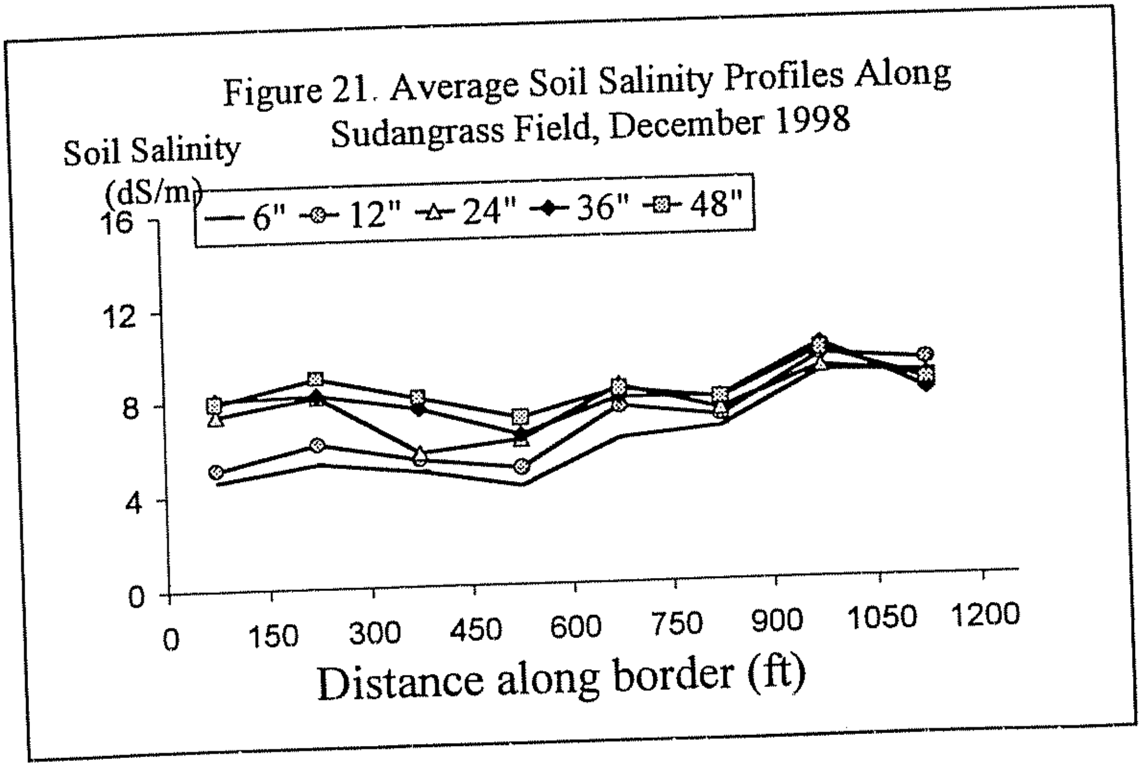


Figure 21. Average Soil Salinity Profiles Along
Sudangrass Field, December 1998
Soil Salinity
(dS/m)
6"
12"
24"
36"
48"
0
4
8
12
16
0
150
300
450
600
750
900
1050
1200
Distance along border (ft)

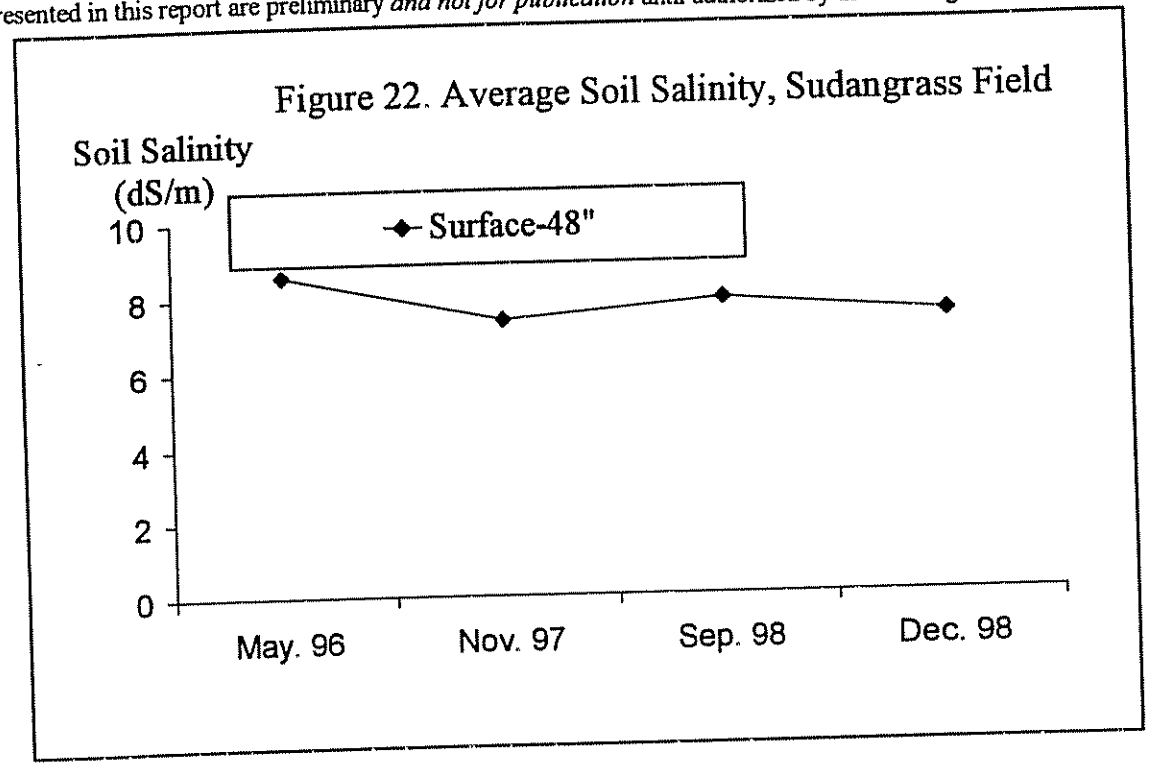


Figure 22. Average Soil Salinity, Sudangrass Field
Soil Salinity (dS/m)
10
8
6
4
2
0
Surface-48"
May. 96
Nov. 97
Sep. 98
Dec. 98

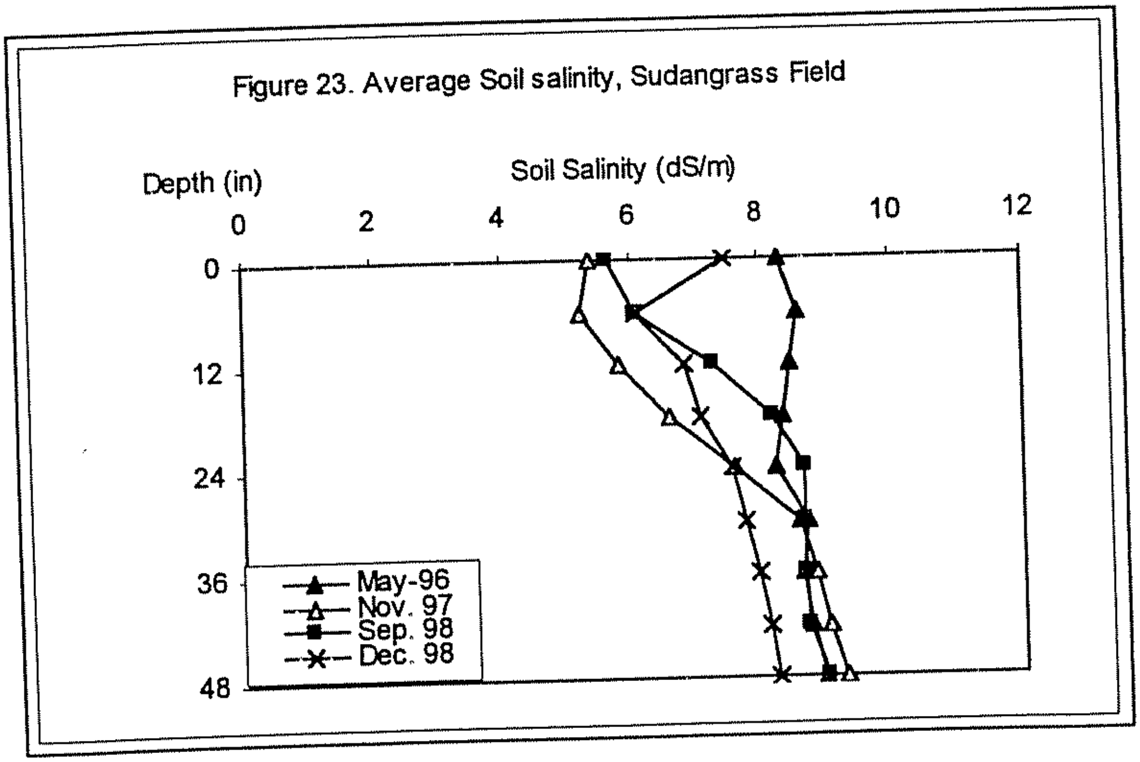


Figure 23. Average Soil salinity, Sudangrass Field
Depth (in)
Soil Salinity (dS/m)
0
2
4
6
8
10
12
0
12
24
36
48
May-96
Nov. 97
Sep. 98
Dec. 98

Figure 24. Average Cl Concentration, Sudangrass Field

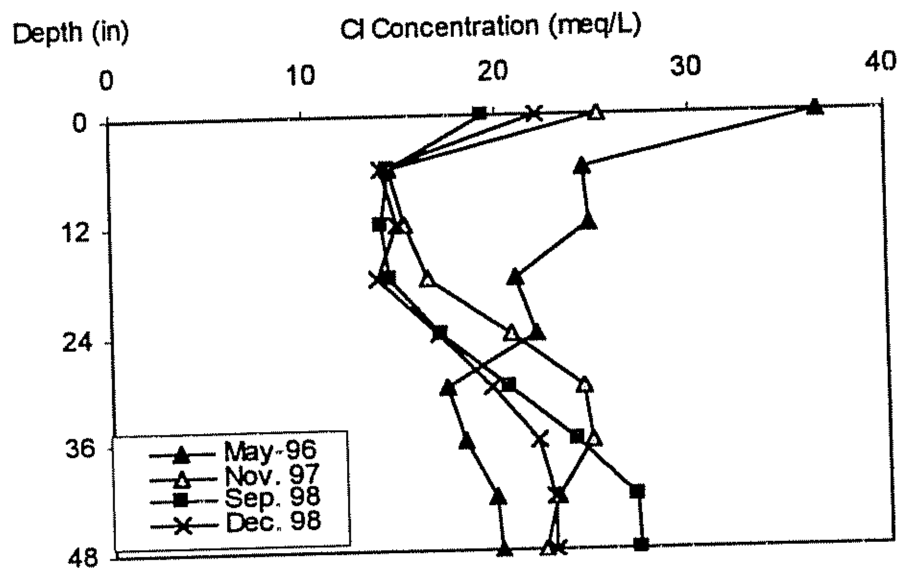


Figure 25. Water table elevation and salinity, Area 70 sudangrass field. 1996

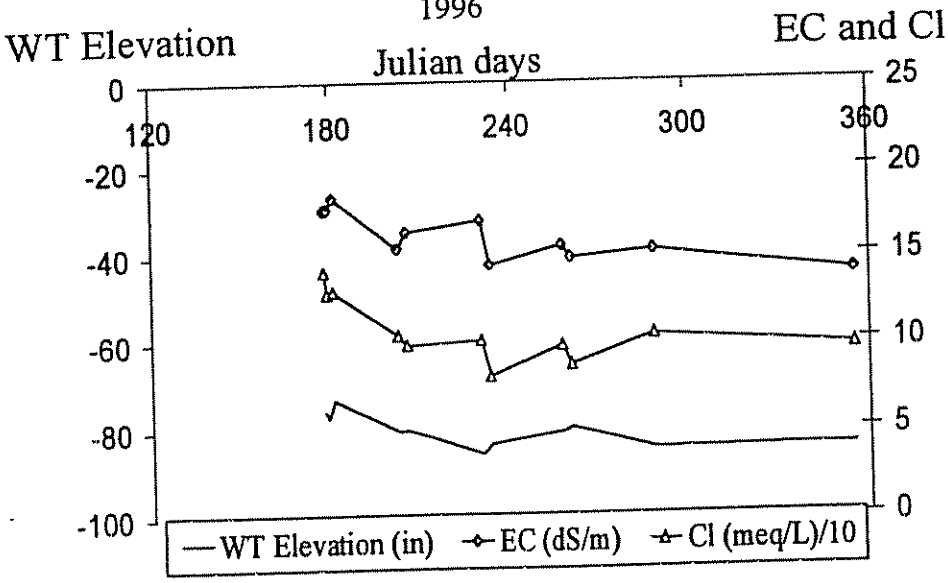


Figure 26. Water table elevation and salinity, Area 70 sudangrass field. 1997

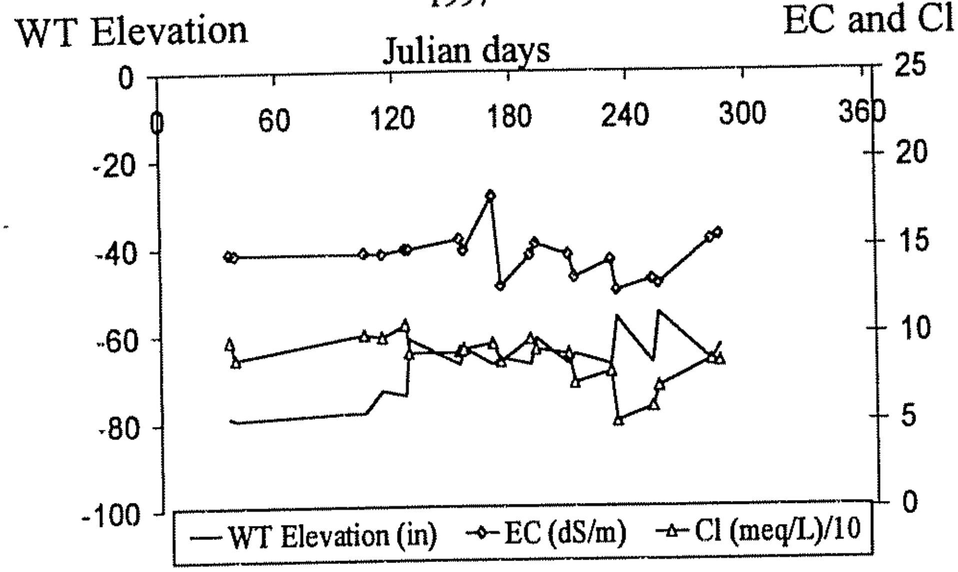


Figure 27. Water table elevation and salinity, Area 70 sudangrass field. 1998

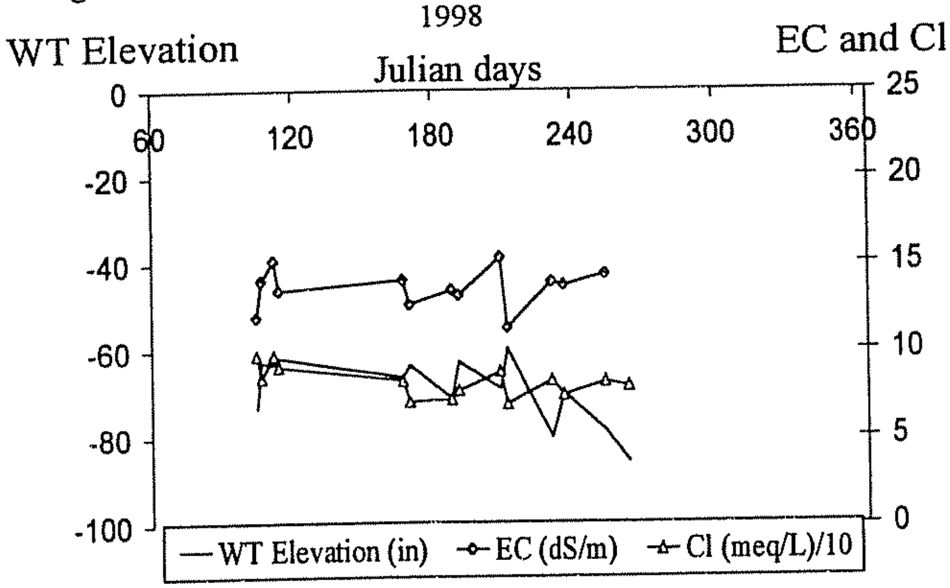


Figure 28. Alfalfa yield distribution along the field (dry tons/ac)

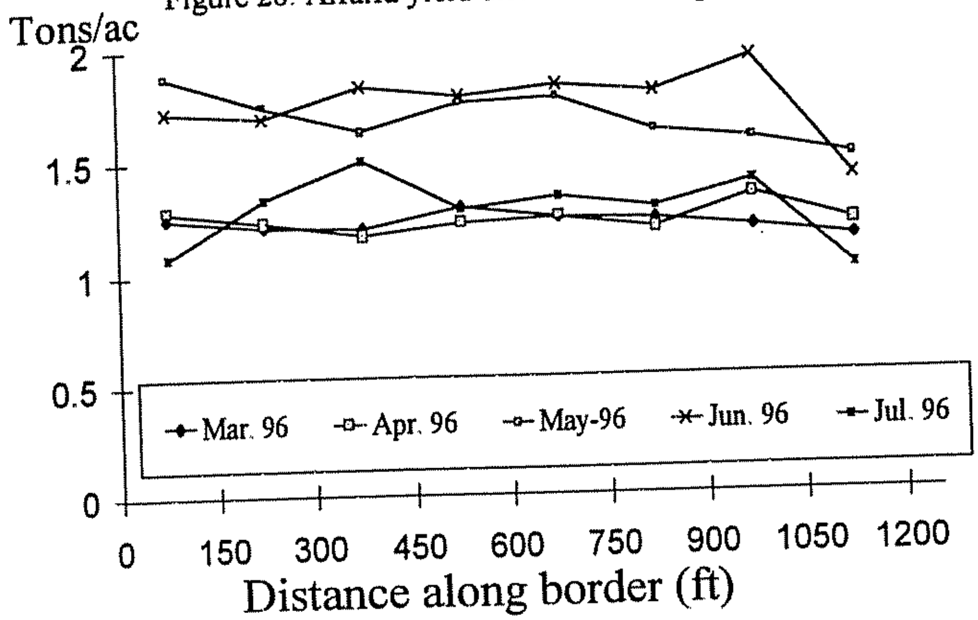


Figure 29. Alfalfa yield distribution along the field (dry tons/ac)

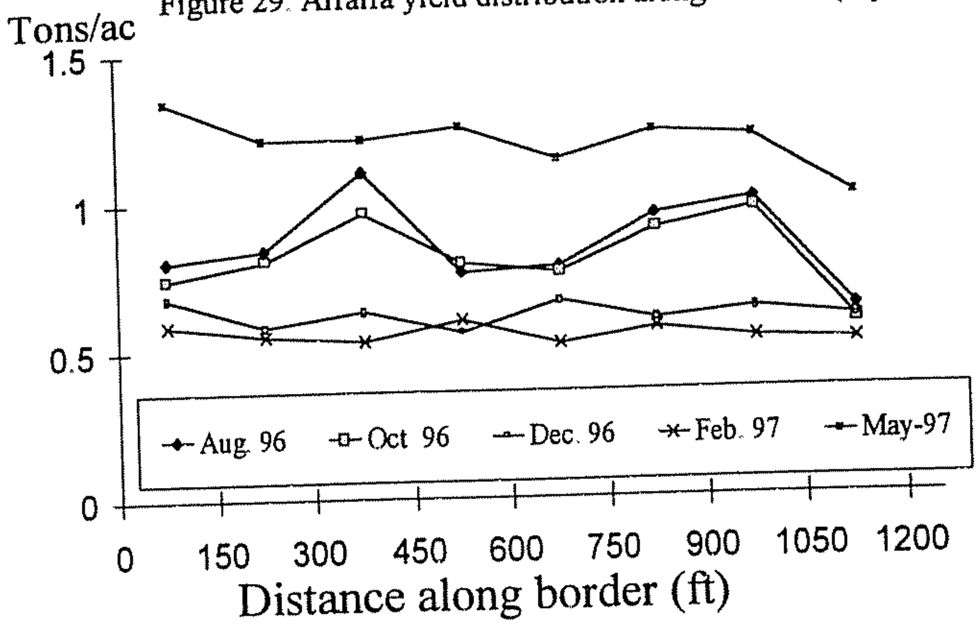


Figure 30. Alfalfa yield distribution along the field (dry tons/ac)

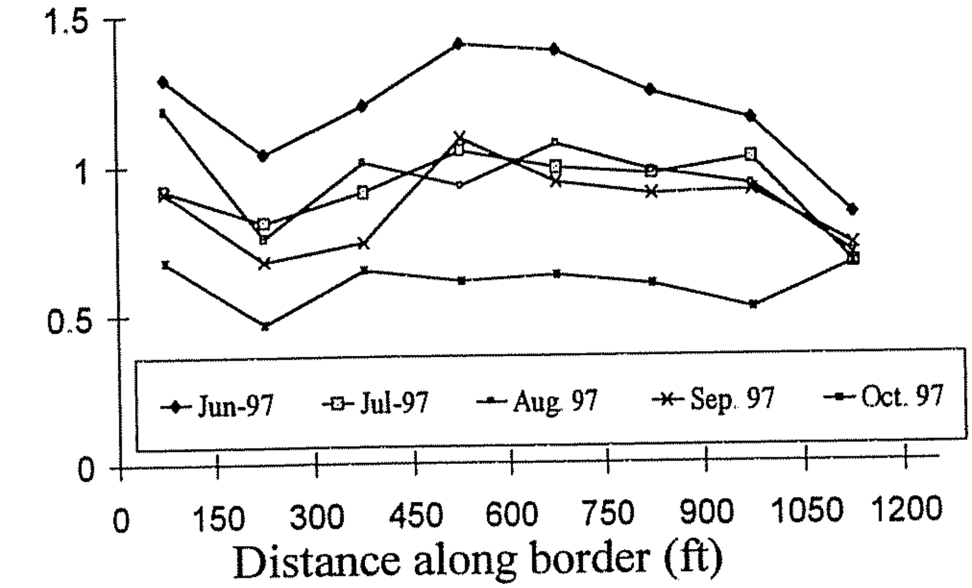


Figure 31. Alfalfa yield distribution along the field (dry tons/ac)

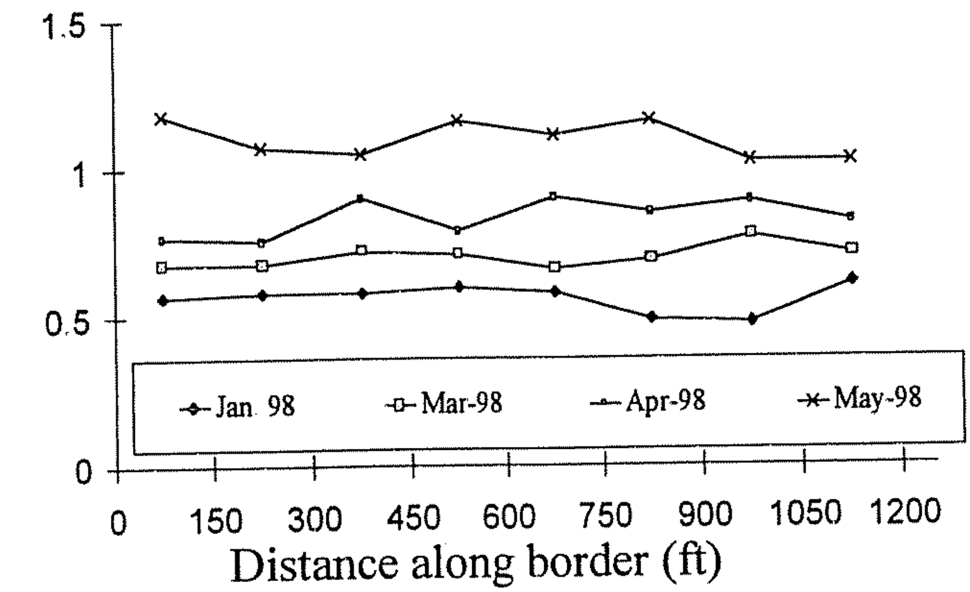


Figure 32. Alfalfa yield distribution along the field (dry tons/ac)

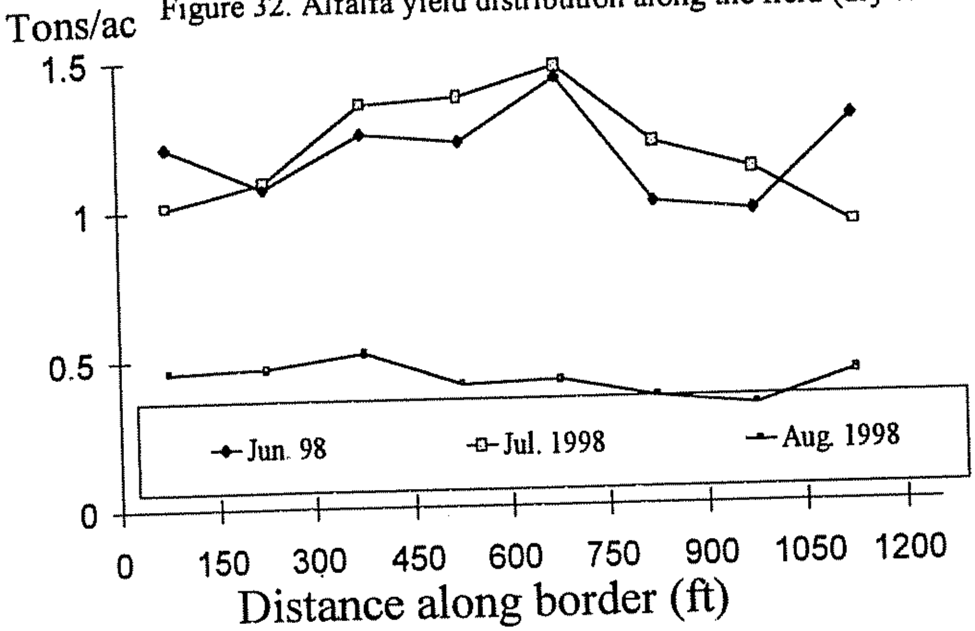


Figure 33. Alfalfa yield distribution along the field (dry tons/ac)

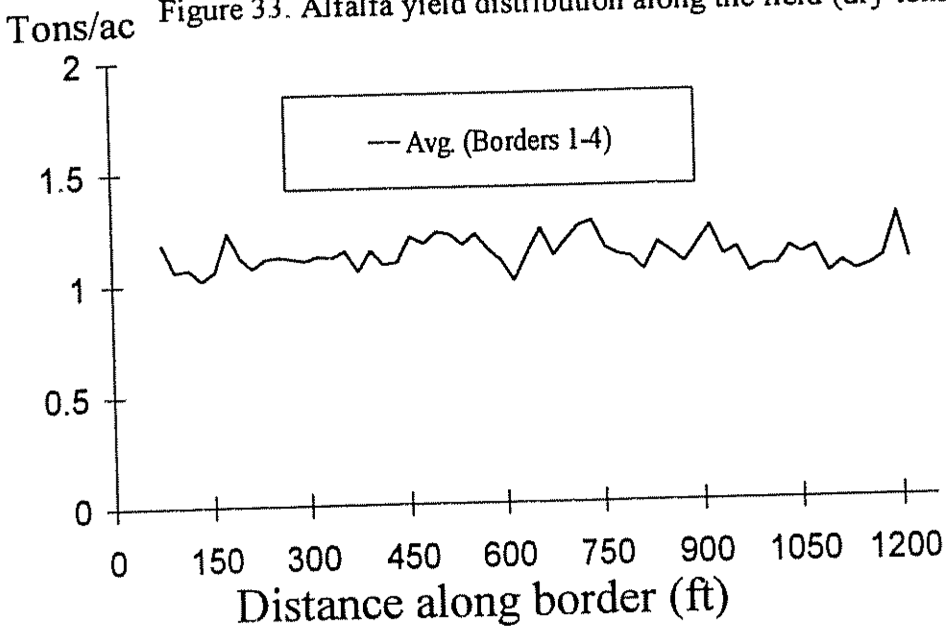


Figure 34. Alfalfa yield distribution along the field.

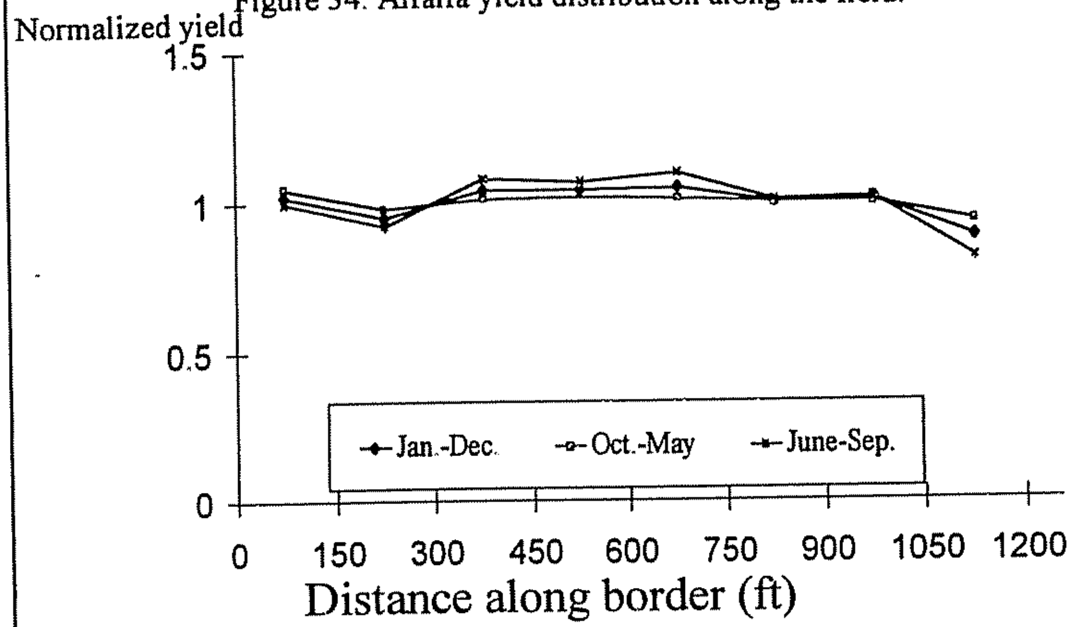


Figure 35. Corn dry mater distribution along the field (dry gm/section)

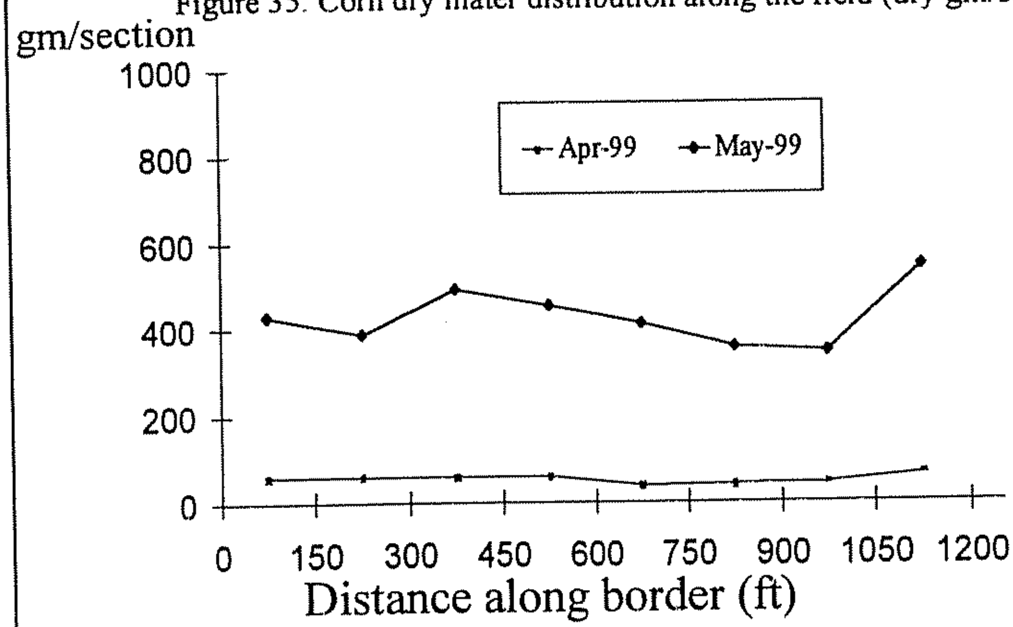


Figure 36. Alfalfa hay quality parameters (May 1997)

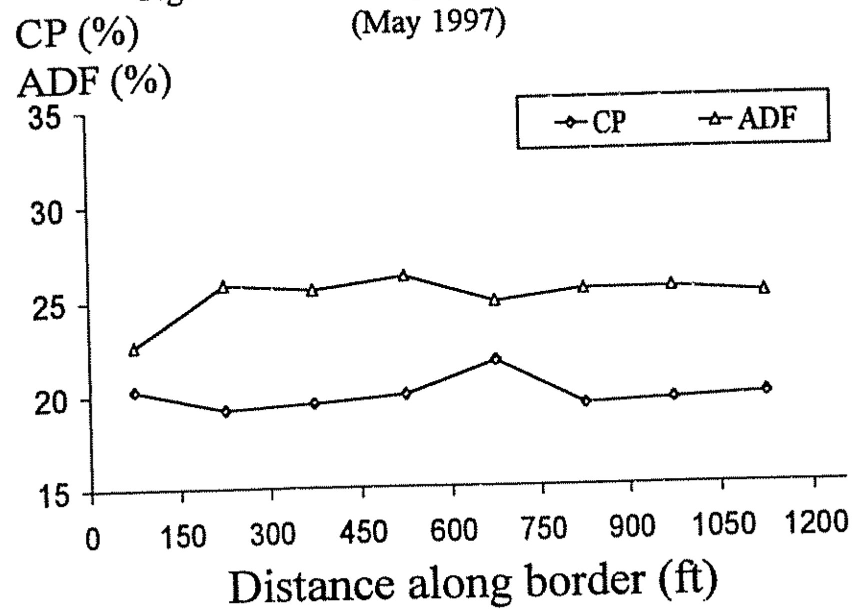


Figure 37. Average Soil Salinity Profiles Along Alfalfa field, November 1995

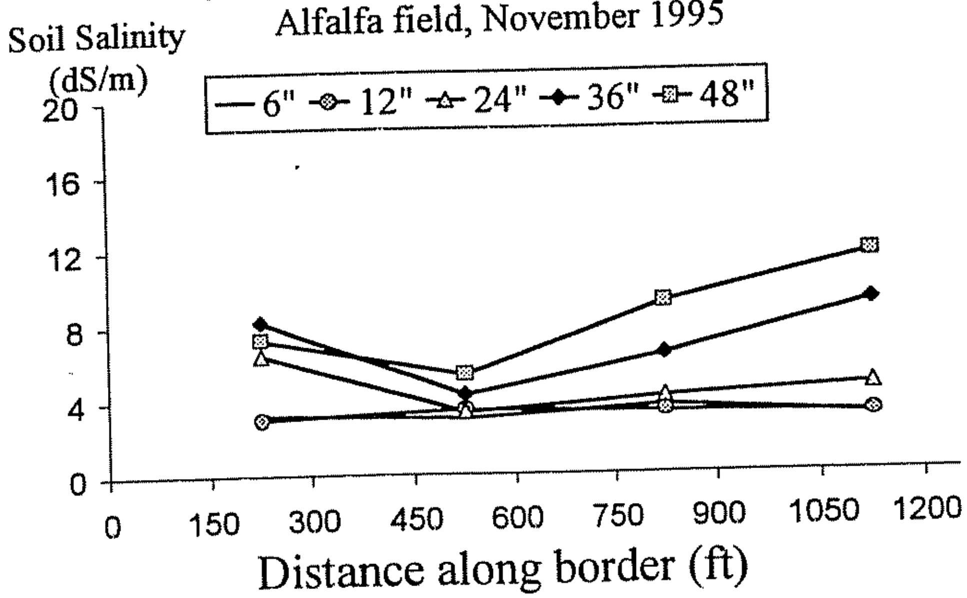


Figure 38. Average Soil Salinity Profiles Along Alfalfa field, January 1996

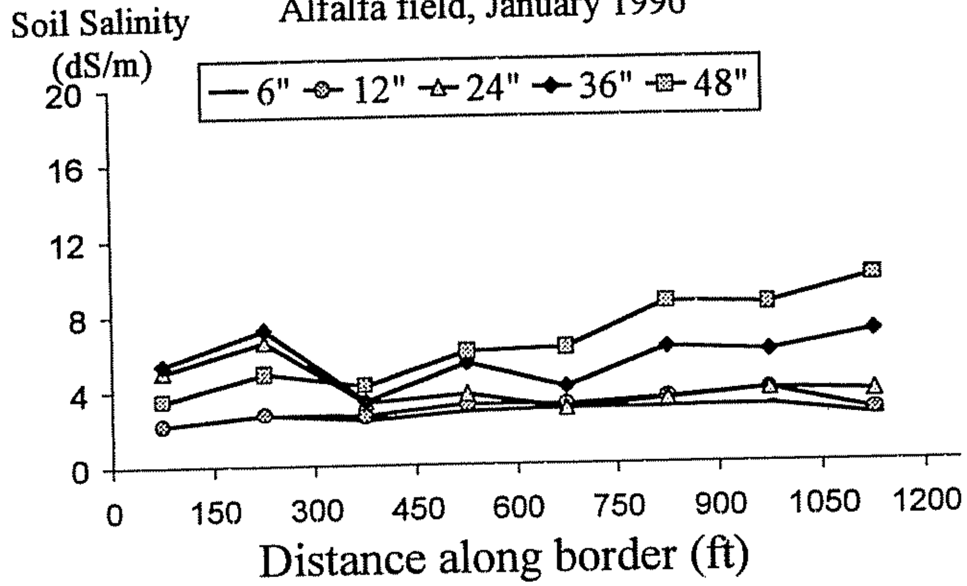


Figure 39. Average Soil Salinity Profiles Along Alfalfa field, November 1996

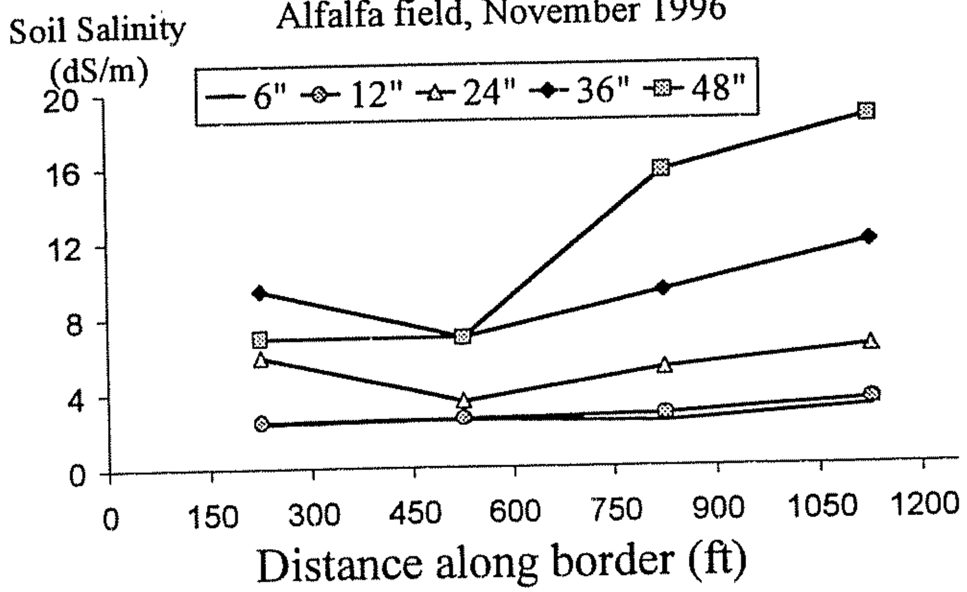


Figure 40. Average Soil Salinity Profiles Along Alfalfa field, March 1997

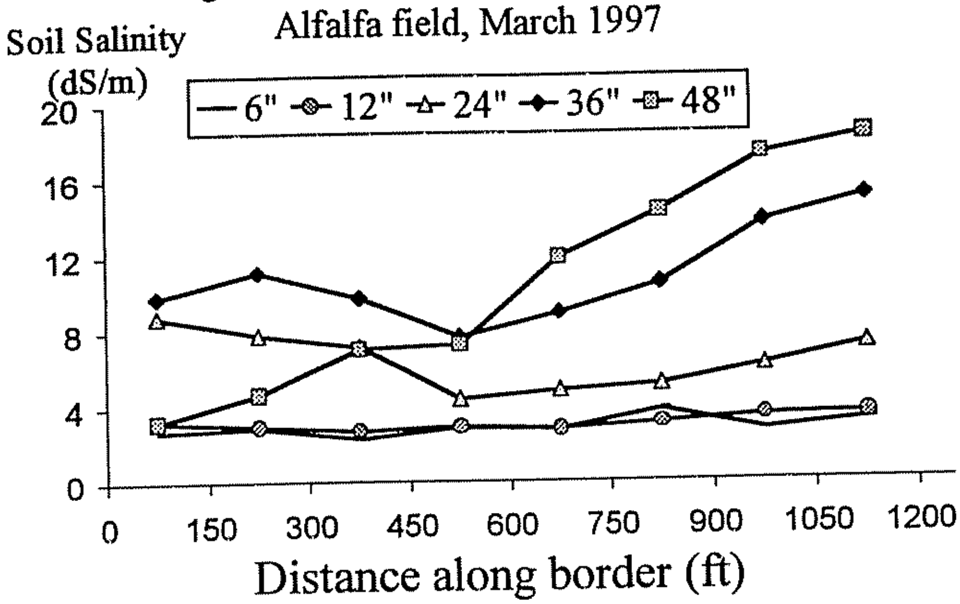


Figure 41. Average Soil Salinity Profiles Along Alfalfa field, October 1997

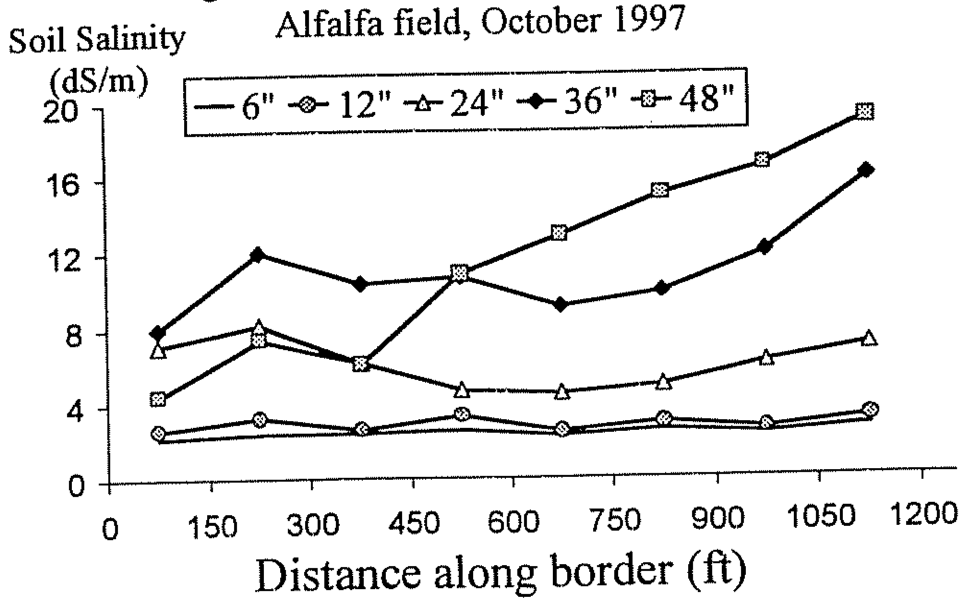


Figure 42. Average Soil Salinity Profiles Along Alfalfa field, August 1998

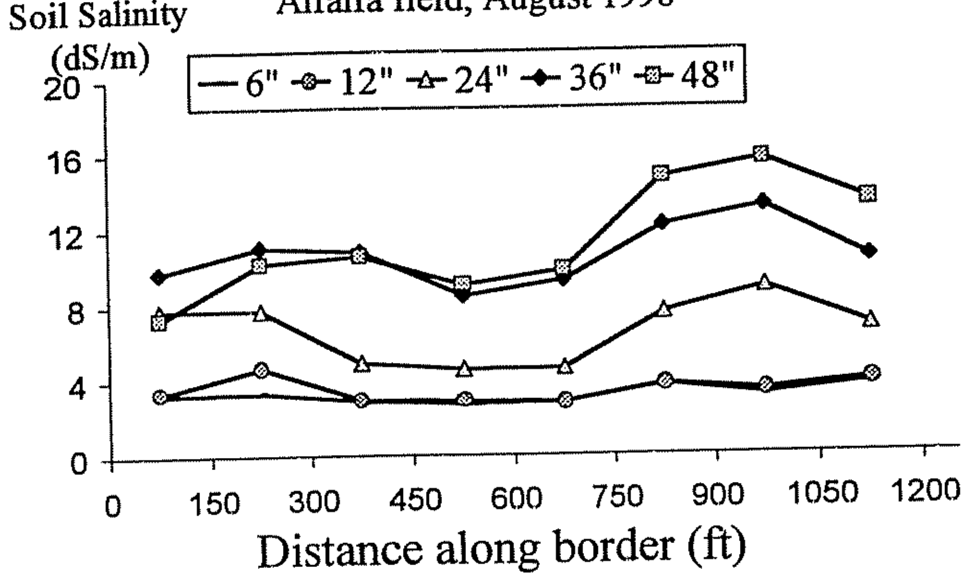


Figure 43. Average Soil Salinity Profiles Along Alfalfa field, November 1998

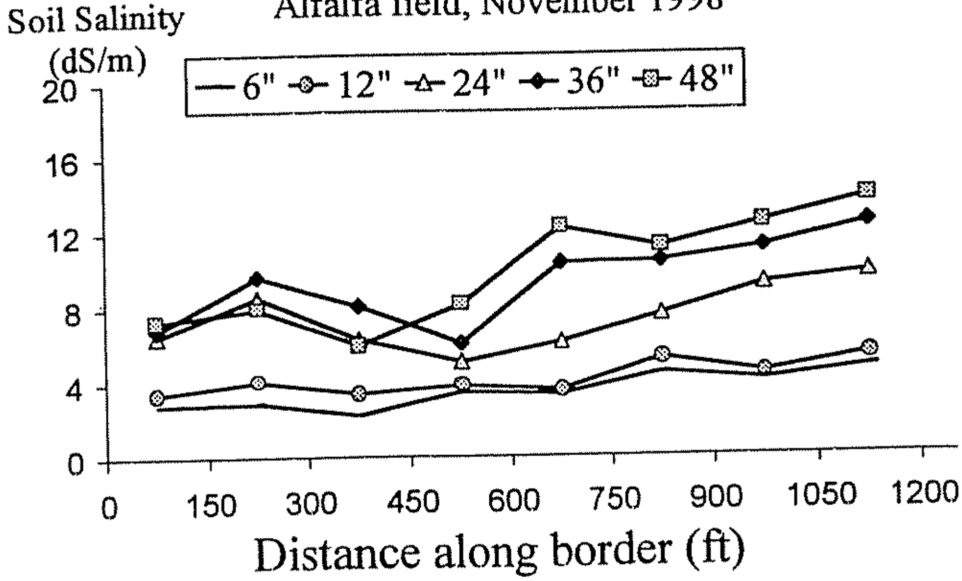


Figure 44. Average Soil Salinity Profiles Along Corn field, May 1999

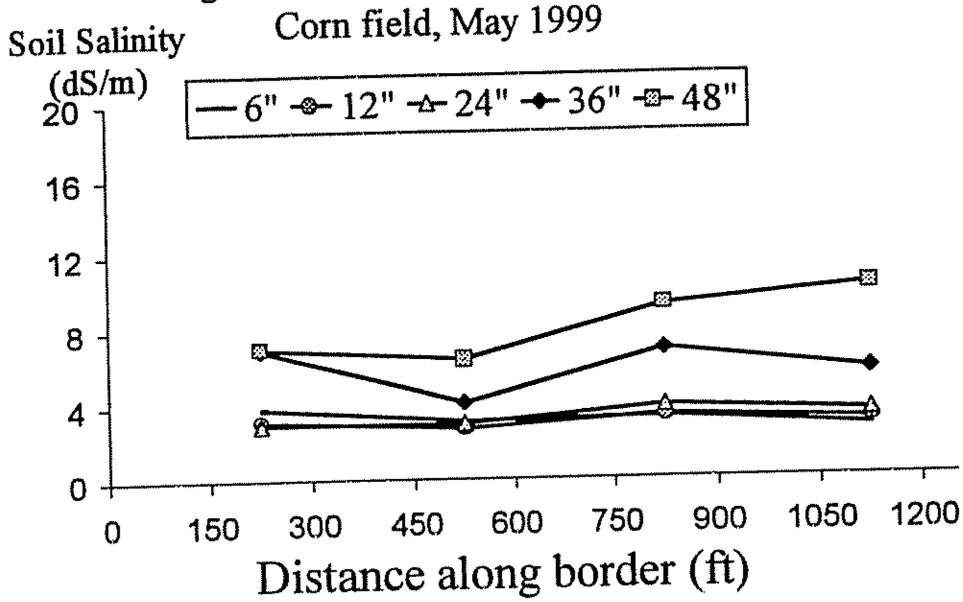


Figure 45. Average Soil Salinity Profiles Along Alfalfa/Corn field

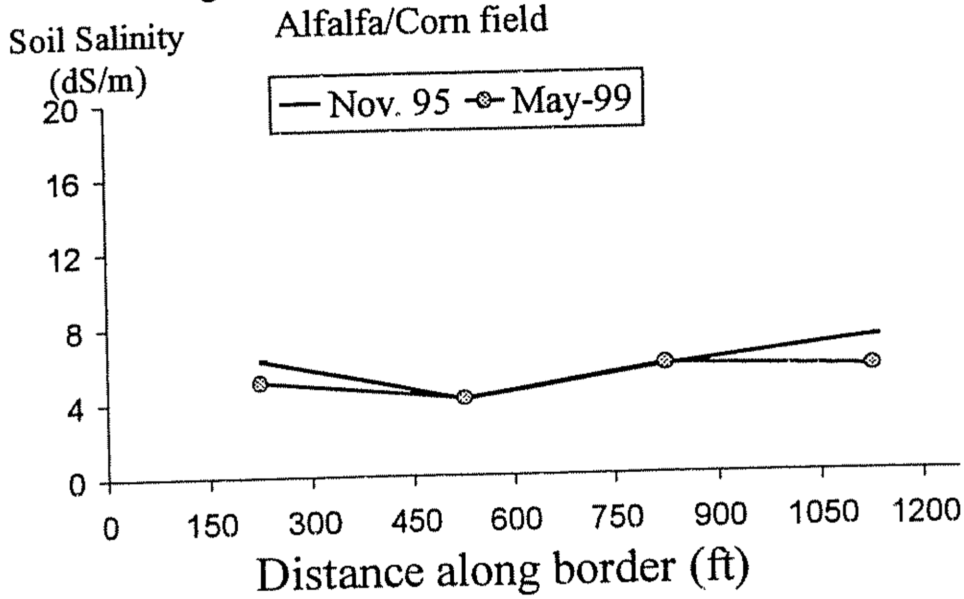


Figure 46. Average Soil salinity, Alfalfa/Corn Field

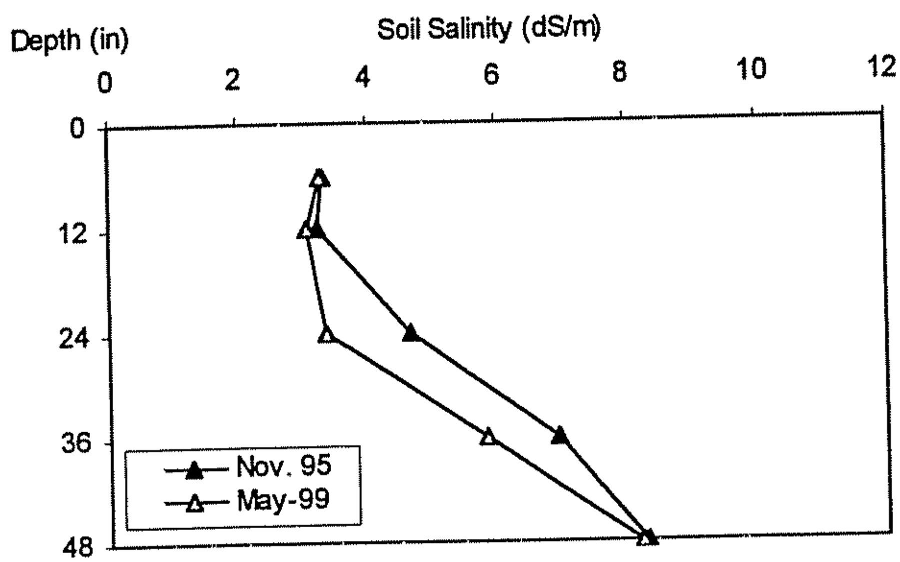


Figure 47. Average Soil Salinity, Alfalfa Field

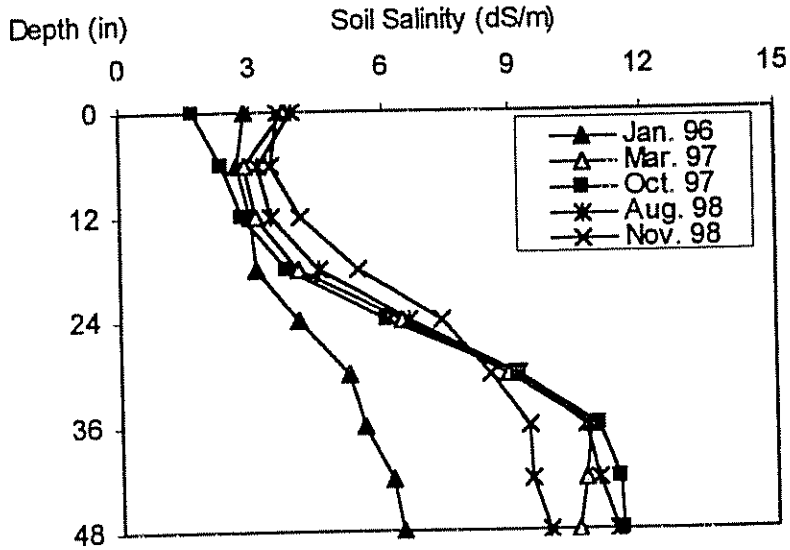


Figure 48. Average Cl Concentration, Alfalfa Field

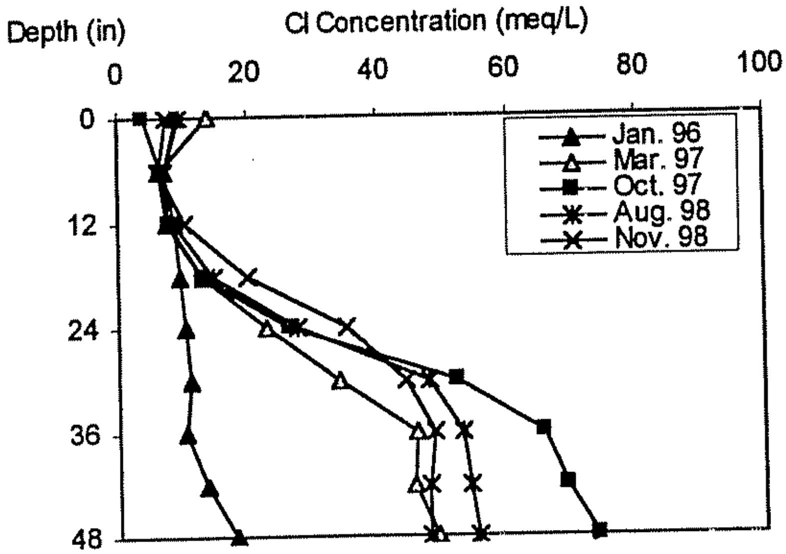


Figure 49. Water table elevation and salinity, Area 80 alfalfa field. 1996-1998

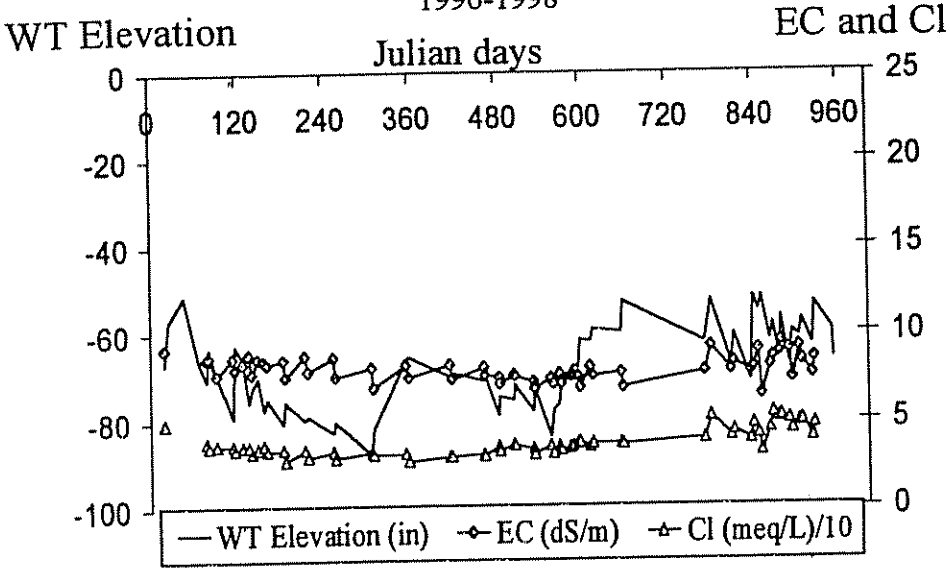


Figure 50. Average and maximum alfalfa root depth.